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Modified semiempirical Stark shifts of ArII lines

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Stark shifts for 47 multiplets of ArII are calculated according to modified semiempirical approach [1], and compared with critically selected [2, 3] experimental data [4 – 11] as well as with semiclassical values of Jones et al. [12], when available. Mean experimental to theoretical (modified semiempirical) shift ratio 1.38 ± 0.60 is obtained.

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1. Introduction

Stark broadening data are of the great need in laboratory and astrophysical plasma spectroscopy. For the evaluation and modelling of the stellar atmospheric physical properties and abundance determinations, astrophysicists require Stark broadening data for a large number of transitions in many atoms. Moreover, Stark shift is one of the important causes of solar and stellar spectral line asymmetries [13, 14], therefore it can serve for more precise determination of other causes of asymmetry, e.g. granular motion [15, 16]. Knowledge of Stark shifts can make possible accurate determination of the gravitational red shifts in spectra of white dwarfs [17 – 19].

Quantum mechanical and semiclassical theories requiring the knowledge of numerous atomic data and time consuming computer codes, are often not suitable for fast or rough Stark broadening estimations, and for large scale calculations. Therefore, efforts had been made to provide simple approximate formulae with good average accuracy [20–22].

A convenient method for Stark broadening calculations when more sophisticated theories are not needed or not applicable (e.g. large scale calculations, lack of atomic data, complex spectra or rough estimates) may be e.g. the modified semiempirical (MSE) approach of Dimitrijević and Konjević [23–25] and Dimitrijević and Kršljanin [1] for Stark broadening parameters of ion lines and the simple method for Stark widths and shifts for neutral atom lines of Dimitrijević and Konjević [26].

MSE approach for ion lines Stark broadening [23–25, 1] was tested several times [27–36, 3, 1] and on the average gives a satisfactory agreement with experiments. It also served as source of Stark broadening data for astrophysical needs [30, 37–39]. The aim of this paper is to test MSE Stark shift theory [1] for the case of a complex ion. For such purposes, the most suitable are ArII lines since for this emitter the most extensive reliable ion line Stark shifts data set exists [4–11]. We took into account 8 experiments [4–11] in 47 multiplets of ArII. Experimental data [4–11] were taken from the critical reviews of experimental data by Konjević and Wiese [2] and Konjević et al. [3].

Argon is one of the important constituents of the Earth's atmosphere, and is frequently used in laboratory plasmas. Absorption lines of ArII are observed in spectra of B and A type stars, where Stark broadening is dominant pressure broadening mechanism.

2. Modified semiempirical approach

According to MSE approach [23, 25, 1], electron impact shift of an ion line [1] is given by the expression:

$$
\begin{aligned}
d = N \frac{4\pi}{3} \frac{\hbar^2}{m^2} \left(\frac{2m\pi}{3kT}\right)^{1/2}
& \cdot \{\mathbf{R}^2_{\ell_i,\ell_i+1} \tilde{g}_{sh}(x_{\ell_i,\ell_i+1}) - \mathbf{R}^2_{\ell_i,\ell_i-1} \tilde{g}_{sh}(x_{\ell_i,\ell_i-1}) \\
& - \mathbf{R}^2_{\ell_f,\ell_f+1} \tilde{g}_{sh}(x_{\ell_f,\ell_f+1}) + \mathbf{R}^2_{\ell_f,\ell_f-1} \tilde{g}_{sh}(x_{\ell_f,\ell_f-1}) \\
& + \sum_{i'} (\mathbf{R}^2_{i'i})_{\Delta n \neq 0}\, g_{sh}(x_{n_i,n_i+1}) \\
& - 2 \sum_{i',\Delta E_{i'i}<0} [(\mathbf{R}^2_{i'i})_{\Delta n \neq 0}\, g_{sh}(x_{i'i})] \\
& - \sum_{f'} (\mathbf{R}^2_{f'f})_{\Delta n \neq 0}\, g_{sh}(x_{n_f,n_f+1}) \\
& + 2 \sum_{f',\Delta E_{f'f}<0} [(\mathbf{R}^2_{f'f})_{\Delta n \neq 0}\, g_{sh}(x_{f'f})] + \sum_k \delta_k \}
\end{aligned}
\tag{1}
$$

Here, $\mathbf{R}^2_{j'j}$ (in units of the Bohr radius a_0^2) is the square of the coordinate operator matrix element summed over all components of the operator and the magnetic substates of total angular momentum J', and averaged over the magnetic substates of J; it can be calculated using the Coulomb approximation [40], so

$$\mathbf{R}^2_{j'j} \approx \left(\frac{3n^*_\ell}{2Z}\right)^2 \frac{\ell}{2\ell_j+1}(n^{*2}_\ell-\ell^2)\,\Phi^2(n^2_{\ell-1}, n^*_\ell, \ell) \qquad (2)$$

$$\sum_{j'}(\mathbf{R}^2_{j'j})_{\Delta n\neq 0} \approx \left(\frac{3n^*_\ell}{2Z}\right)^2 \frac{1}{9}(n^{*2}_j+3\ell^2_j+3\ell_j+11), \qquad j=i,f \qquad (3)$$

(ℓ_j is the orbital quantum number of the valence electron, ℓ is $\max(\ell'_j, \ell_j)$ and Φ^2 is the Bates-Damgaard factor, tabulated e.g. in [41]). The cases where one-electron model assumed in (2) and (3) is not satisfied are analysed in detail by Dimitrijević [31]. Other symbols have the usual meaning: i and f denote the initial and final energy states, $x_{j'j}=3kT/2|\Delta E_{j'j}|$, $x_n=3kTn^{*3}/4Z^2E_H$ (E_H is the hydrogen ionization energy, Z is the residual ionic charge), $\Delta E_{j'j}=E_{j'}-E_j$; $n^*_j=[E_HZ^2/(E_{\text{ion}}-E_j)]^{1/2}$ (E_{ion} is the appropriate spectral series limit, and N is the electron number density).

Gaunt factor $\tilde{g}_{sh}$ for different ionization stages is evaluated in [1] solving Cauchy integral dispersion relation on the basis of Kobzev's [42] scaling law for threshold values, semiclassical Stark broadening functions for hyperbolic [43, 44] and straight [45] perturber paths and GBKO high temperature limit [45]. Both $\tilde{g}_{sh}$ and g_{sh} are tabulated in [1].

Equation (1) is obtained assuming the LS coupling approximation, separating the transitions with $\Delta n\neq 0$ and supposing that the nearest perturbing level in the $n\neq 0$ group may be obtained in the hydrogenic approximation as $|\Delta E_{n,n+1}|\approx 2Z^2E_H/n^{*3}$. The sum $\sum_k \delta_k$ in (1) is not equal to zero only if perturbing levels strongly violating the assumed approximations exist, i.e. if there are levels with $|\Delta E_{j'j}|\ll|\Delta E_{n,n+1}|$. Contribution of each such level should be calculated as

$$\delta_i=\pm(\mathbf{R}^2_{i'i})\,[g_{sh}(x_{i'i})\mp g_{sh}(x_{n_i,n_i+1})]$$

or

$$\delta_f=\mp(\mathbf{R}^2_{f'f})\,[g_{sh}(x_{f'f})\mp g_{sh}(x_{n_f,n_f+1})] \qquad (4)$$

where lower signs corresponds to $\Delta E_{j'j}<0$.

MSE formula for ion lines Stark widths is tested several times for singly, doubly and triply charged ions [27–36, 3] and discrepancy with experimental data does not exceed 50% on the average (e.g. [3]). Reliable results are obtained even for heavier ions, as TiII and MnII [30], and FeII [37] especially interesting in astrophysics. Formula for Stark shifts (1) lead to good results in the case of 8 multiplets of BeII, MgII, CaII, AlII and ArII [1], but extensive quantitative testing of this formula had not been performed, until now.

3. Results and discussion

Results of our computations of ArII Stark shifts are compared in Tables 1–3 and in Figs. 1–5 with available experimental data [4–11] and with semiclassical results of Jones et al. [12].

Generally, the possibilities of theory in the case of shifts are considerably smaller then for the line widths [46, 44]. Experimental data on ion lines Stark shifts exist almost exclusively for singly charged ions. Most extensive reliable experimental data set exists in the case of ArII. There are about 170 experimental results for line shifts within 47 allowed and forbidden multiplets. Semiclassical line shift calculations of Jones et al. [12] cover only 12 multiplets from this set. We performed MSE computations covering all reliable data, and our results are listed in Table 1, as measured to theoretical line shift ratios d_m/d_{th},together with the same ratios for semiclassical results [12], when available. In the cases where experimental results are equal to zero, we took $d_m/d_{th}=1$ if the theoretical results are less than the last important figure (e.g. experimental and theoretical results for 1 UV multiplet are 0.00 and 0.0002 respectively, so we found $d_m/d_{th}=1$). Data on atomic energy levels used in our calculations were taken from [47].

We averaged d_m/d_{th} results for all line shift measurements. The cases with opposite signs between experimental and theoretical line shifts were excluded from the averaging; they are especially marked and separately counted. Line shifts in the multiplets 32 and $4s\,^2P-4p'\,^2P^0$ show big differences within the multiplets (see e.g. [48, 49]) because of the irregular structure and mixing of the upper perturbing energy levels. Therefore, our results obtained for multiplets as a whole show poor agreement with single line experiments, so we excluded these two cases from the averaging.

Mean d_m/d_{th} ratio for 165 line shift measurements is 1.38±0.60 in the case of MSE formula (1) (with 6 results with opposite signs of the shifts). Our analysis of the semiclassical results [12], for 98 line shift measurements gives $d_m/d_{th}=1.06\pm 0.53$, with 4 results with opposite signs.

One should especially emphasize the fact that our computations cover a number of forbidden multiplets

Table 1. Comparison of MSE and semiclassical [12] ArII Stark line shifts with reliable experimental data [4–11], at $N_e=10^{17}$ cm^{-3}. Columns are: (1) transition arrays, (2) multiplets, (3) line wavelengths, (4) electron temperatures of the experiments, (5) experimental shifts at $N_e=10^{17}$ cm^{-3}, (6) accuracy (data in columns 1–6 were taken from [2, 3, 11]; accuracy of the experiment [11] is estimated according to criteria of [2, 3]), (7) reference numbers of the experiments, (8) experimental to theoretical line shifts ratios for semiclassical results [12], and (9) the same ratios for present MSE results. Cases where experimental and theoretical shifts have the opposite signs are denoted by asterisks

Transition array (1)	Multiplet (2)		λ[Å] (3)	$T[K]$ (4)	d_m[Å] (5)	A. (6)	R. (7)	d_m/d_{th}^{sc} (8)	d_m/d_{th}^{MSE} (9)
$3s^2 3p^5$–$3s 3p^6$	$^2P^0-{}^2S$	(1*UV*)	919.78	25000	0.00		10		1
			932.05	25000	0.00		10		1
$3p^4 3d$–$3p^4(^3P)4p$	$^4D-{}^4P^0$	(1)	4400.99	13800	0.050	*B*	4	0.55	1.52
				20000	0.067	*C*	6	0.83	2.45
			4371.33	13800	0.060	*B*	4	0.67	1.83
				20000	0.061	*C*	6	0.75	2.23
				16500	0.07	*C*	5	0.88	2.32
			4332.03	20000	0.061	*C*	6	0.75	2.23
			4431.00	13800	0.070	*B*	4	0.78	2.13
			4400.10	13800	0.050	*B*	4	0.55	1.52
				20000	0.067	*C*	6	0.83	2.45
			4352.20	13800	0.050	*B*	4	0.55	1.52
				20000	0.061	*C*	6	0.75	2.23
			4420.91	20000	0.061	*C*	6	0.75	2.23
	$^4D-{}^4D^0$	(2)	4013.86	13800	0.098	*B*	4	1.18	2.66
				20000	0.044	*C*	6	0.59	1.43
				16500	0.09	*C*	5	1.13	2.66
			3968.36	13800	0.099	*B*	4	1.19	2.69
				20000	0.044	*C*	6	0.59	1.43
			3914.77	20000	0.033	*C*	6	0.45	1.07
			3944.27	20000	0.050	*C*	6	0.68	1.63
			3875.26	20000	0.027	*C*	6	0.38	0.88
			4038.81	20000	0.044	*C*	6	0.59	1.43
			3992.05	20000	0.044	*C*	6	0.59	1.43
	$^4D-{}^4S^0$	(5)	3499.48	20000	0.056	*C*	6		2.39
$3p^4(P)3d-3p^4(^2D)4p'$	$^2P-{}^2D^0$	(30)	3605.88	20000	0.039	*C*	6		*
	$^2D-{}^2D^0$	(39)	4481.81	16500	0.08	*C*	5		*
$3p^4 4s-3p^4(^3P)4p$	$^4P-{}^4P^0$	(6)	4806.02	11800	−0.075	*B*	7	0.93	1.32
				13000	−0.075	*B*	7	1.12	1.44
				13800	−0.090	*B*	4	1.45	1.78
				13900	−0.068	*C*	5	1.11	1.35
				20000	−0.033	*C*	6	1.57	0.78
				16500	−0.08	*C*	5	2.0	1.73
				16500	−0.050	*C*	11	1.53	1.08
				17400	−0.048	*C*	11	1.66	1.06
				18000	−0.0	*C*	11	1	1
				18700	−0.040	*C*	11	1.63	0.92
			4933.21	16500	−0.08	*C*	5	2.0	1.73
			4735.91	13900	−0.076	*C*	8	1.24	1.50
				20000	−0.044	*C*	6	2.09	1.04
				16500	−0.10	*C*	5	2.5	2.16
			4847.82	13800	−0.087	*B*	4	1.40	1.72
				20000	−0.044	*C*	6	2.09	1.04
				16500	−0.08	*C*	5	2.0	1.73
				16500	−0.050	*C*	11	1.53	1.08
				18000	−0.036	*C*	11	1.34	0.81
				18700	−0.050	*C*	11	2.03	1.15
			5009.33	13800	−0.090	*B*	4	1.45	1.78
				16500	−0.08	*C*	5	2.0	1.73
	$^4P-{}^4D^0$	(7)	4348.06	14500	−0.017	*C*	9	0.36	0.62
				15600	−0.022	*C*	9	0.55	0.83
				13800	−0.050	*B*	4	0.98	1.76
				13900	−0.031	*C*	8	0.61	1.10
				20000	−0.039	*C*	6	2.29	1.65
				16500	−0.06	*C*	5	1.50	2.31
				16200	−0.032	*C*	11	1.15	1.22

Table 1 (continued)

Transition array (1)	Multiplet (2)	λ[Å] (3)	$T[K]$ (4)	d_m[Å] (5)	A. (6)	R. (7)	d_m/d_{th}^{sc} (8)	d_m/d_{th}^{MSE} (9)
			16500	−0.033	*C*	11	1.24	1.27
			17400	−0.034	*C*	11	1.44	1.34
			18000	−0.027	*C*	11	1.23	1.09
			18700	−0.030	*C*	11	1.50	1.23
		4426.01	13800	−0.055	*B*	4	1.08	1.94
			20000	−0.033	*C*	6	1.94	1.40
			16500	−0.06	*C*	5	1.5	2.31
		4430.19	13800	−0.058	*B*	4	1.14	2.04
			16500	−0.08	*C*	5	2.0	3.08
		4266.53	20000	−0.033	*C*	6	1.94	1.40
			16500	−0.07	*C*	5	1.8	2.69
		4331.20	13800	−0.042	*B*	4	0.82	1.48
			20000	−0.028	*C*	6	1.65	1.19
		4379.67	13800	−0.044	*B*	*4*	0.86	1.55
			16500	−0.08	*C*	5	2.0	3.08
		4178.37	20000	−0.028	*C*	6	1.65	1.19
		4282.90	20000	−0.033	*C*	6	1.94	1.40
	$^4P-^2D^0$ (8)	4082.39	20000	−0.039	*C*	6		1.07
		4228.16	13800	−0.01	*D*	4		0.22
	$^4P-^4S^0$ (10)	3729.31	20000	−0.033	*C*	6	*	1.92
			16500	0.08	*C*	5	1.00	*
		3850.58	13800	−0.001	*C*	4	*	0.05
			20000	−0.050	*C*	6	*	2.91
		3928.63	13800	−0.001	*C*	4	*	0.05
	$^2P-^4D^0$ (13)	5145.32	16500	0.05	*C*	5		*
	$^2P-^2D^0$ (14)	4879.86	13900	−0.039	*C*	8	0.23	0.53
			20000	−0.056	*C*	6	0.38	0.90
			16500	−0.05	*C*	2	0.31	0.74
		4726.86	13800	−0.078	*B*	4	0.47	1.05
			20000	−0.044	*C*	6	0.30	0.71
	$^2P-^2P^0$ (15)	4545.05	13800	−0.052	*B*	4		0.57
			20000	−0.028	*C*	6		0.37
			16500	0.08	*C*	5		*
		4657.89	13800	−0.055	*B*	4		0.60
			20000	−0.017	*C*	6		0.23
			16500	0.08	*C*	5		*
		4764.86	13800	−0.052	*B*	4		0.57
			20000	−0.028	*C*	6		0.37
			16500	0.10	*C*	5		*
	$^2P-^2S^0$ (17)	4375.95	20000	0.0		6		1
		4579.35	13800	−0.029	*B*	4		0.38
			20000	0.0		6		1
			16500	0.0	*C*	5		1
$3p^4 4s$–$3p^4(^1D)4p'$	$^2P-^2P^0$ (19)	2942.89	20000	0.12	*C*	6		12.9
	$^2P-^2D^0$ (16*UV*)	2844.13	20000	−0.022	*C*	6		0.85
		2847.82	20000	−0.017	*C*	6		0.65
$3p^4 4s'$–$3p^4(^1D)4p'$	$^2D-^2F^0$ (31)	4609.56	13800	−0.048	*B*	4		1.13
			20000	0.0		6		1
			16500	−0.05	*C*	5		1.29
		4589.90	13800	−0.047	*B*	4		1.11
			20000	0.0		6		1
	$^2D-^2P^0$ (32)	4277.52	20000	0.16	*C*	6		5.93
		4237.22	20000	0.16	*C*	6		5.93
	$^2P-^2D^0$ (33)	4079.58	20000	−0.044	*C*	6		0.59
$3p^4 4p$–$3p^4(^3P)4d$	$^4P^0-^4D$ (44)	3514.39	20000	0.24	*C*	6		1.71
		3535.32	20000	0.25	*C*	6		1.78
		3509.78	20000	0.22	*C*	6		1.57
		3454.10	20000	0.22	*C*	6		1.57
	$^4D^0-^4D$ (54)	3780.84	20000	0.25	*C*	6	0.83	1.60
		3826.81	20000	0.22	*C*	6	0.73	1.41

Table 1 (continued)

Transition array (1)	Multiplet (2)		λ[Å] (3)	$T[K]$ (4)	d_m[Å] (5)	A. (6)	R. (7)	d_m/d_{th}^{sc} (8)	$d_m/d_{th}^{\mathrm{MSE}}$ (9)
			3872.14	20000	0.22	*C*	6	0.73	1.41
			3880.34	20000	0.19	*C*	6	0.63	1.22
			3763.50	20000	0.27	*C*	6	0.89	1.73
			3799.38	20000	0.21	*C*	6	0.70	1.35
			3841.52	20000	0.18	*C*	6	0.60	1.15
			3900.62	20000	0.25	*C*	6	0.83	1.60
			3911.57	20000	0.24	*C*	6	0.79	1.54
	$^4D^0-{}^4F$	(56)	3520.00	20000	0.24	*C*	6		1.26
			3548.52	20000	0.28	*C*+	6		1.46
	$^4D^0-{}^4P$	(57)	3370.93	20000	0.23	*C*	6		1.06
			3421.62	20000	0.25	*C*	6		1.16
			3565.03	20000	0.30	*C*+	6		1.39
			3480.51	20000	0.25	*C*	6		1.16
	$^4D^0-{}^2F$	(59)	3397.90	20000	0.28	*C*+	6		1.38
			3430.42	20000	0.23	*C*	6		1.13
	$^2D^0-{}^4D$	(65)	3988.16	20000	0.22	*C*	6		1.14
	$^2D^0-{}^2F$	(70)	3464.13	20000	0.28	*C*+	6	0.81	1.20
	$^2D^0-{}^2P$	(71)	3137.63	20000	0.21	*C*	6		0.57
	$^2P^0-{}^2P$	(83)	3293.64	20000	0.31	*C*+	6	0.57	0.80
			3307.29	20000	0.37	*C*+	6	0.68	0.95
			3366.59	20000	0.29	*C*+	6	0.53	0.74
	$^4S^0-{}^4P$	(90)	3868.52	20000	0.33	*C*+	6	0.91	1.28
			3932.55	20000	0.31	*C*+	6	0.85	1.21
			3979.36	20000	0.35	*C*+	6	0.96	1.36
	$^2S^0-{}^2P$	(96)	3388.53	20000	0.24	*C*	6		0.58
$3p^44p'$–$3P^4(^1D)\,4d'$	$^2F-{}^2D^0$	(107)	3414.64	20000	0.43	*C*+	6		2.31
	$^2F^0-{}^2F$	(109)	3376.44	20000	0.37	*C*+	6		1.91
			3350.93	20000	0.29	*C*+	6		1.49
			3365.54	20000	0.34	*C*+	6		1.75
	$^2P^0-{}^2D$	(116)	3660.44	20000	0.27	*C*	6		1.64
			3639.83	20000	0.25	*C*	6		1.52
	$^2D^0-{}^2D$	(129)	3803.17	20000	0.34	*C*+	6		1.40
	$^2D^0-{}^2F$	(131)	3737.89	20000	0.38	*C*+	6		1.51
			3718.21	20000	0.36	*C*+	6		1.43
			3724.52	20000	0.33	*C*+	6		1.31
$3p^44p$–$3p^4(^3P)\,5s$	$^4P^0-{}^4P$	(42)	3720.43	20000	0.33	*C*+	6	0.96	1.11
			3669.61	20000	0.42	*C*+	6	1.22	1.41
			3678.27	20000	0.35	*C*+	6	1.01	1.17
			3622.14	20000	0.33	*C*+	6	0.96	1.11
			3809.46	20000	0.32	*C*+	6	0.93	1.07
			3770.52	20000	0.28	*C*+	6	0.81	0.94
	$^4P^0-{}^2P$	(43)	3650.89	20000	0.36	*C*+	6		1.26
	$^4D^0-{}^4P$	(52)	4033.82	20000	0.38	*C*+	6		1.08
			4179.30	20000	0.37	*C*+	6		1.05
			4156.09	20000	0.40	*C*+	6		1.14
	$^2D^0-{}^2P$	(64)	4218.67	20000	0.43	*C*+	6	0.94	1.12
	$^2P-{}^2P^0$	(77)	4222.64	20000	0.39	*C*+	6		0.94
			4129.69	20000	0.38	*C*+	6		0.92
$3p^44p$–$3p^4(^1D)\,5s'$	$^2P^0-{}^2D$	(17*UV*)	2806.17	20000	0.18	*C*	6		1.06
$3p^44p'$–$3p^4(^1D)\,5s'$	$^2F^0-{}^2D$	(105)	3946.10	20000	0.37	*C*+	6		1.17
			3925.72	20000	0.38	*C*+	6		1.21
$3d'\,^2F$–$(^3P)\,4f\,[4]^0$			3046.08	20000	0.13	*C*	6		1.85
			3066.89	20000	0.12	*C*	6		1.71
$3d'\,^2D$–$(^1D)\,4f\,[3]^0$			2708.27	20000	0.13	*C*	6		2.48
			2744.80	20000	0.10	*C*	6		1.91
$3d'\,^2D$–$(^1D)\,4f\,[2]^0$			2732.50	20000	0.17	*C*	6		3.16
			2769.75	20000	0.15	*C*	6		2.79
$3d'\,^2P$–$(^1D)\,4f\,[2]^0$			2931.48	20000	0.13	*C*	6		1.46
$3d'\,^2P$–$(^1D)\,4f\,[1]^0$			2960.26	20000	0.067	*C*	6		0.74

Table 2. Mean ratios of measured to theoretical ArII Stark shifts for different multiplets, together with standard deviations and numbers of line shifts involved (in brackets). SC are the semiclassical calculations [12] and MSE are the present calculations. Reference numbers of the experiments are also indicated.

Transition multiplet			SC	MSE	Ref.
$3d-4p$	$^4D-^4P^0$	(1)	0.72±0.11 (12)	2.05±0.34 (12)	[4–6]
	$^4D-^4D^0$	(2)	0.74±0.29 (10)	1.66±0.70 (10)	[4–6]
$4s-4p$	$^4P-^4P^0$	(6)	1.62±0.41 (22)	1.36±0.38 (22)	[4–8, 11]
	$^4P-^4D^0$	(7)	1.38±0.51 (24)	1.63±0.64 (24)	[4–6, 8, 9, 11]
	$^4P-^2D^0$	(8)		0.64±0.42 (2)	[4, 6]
	$^4P-^4S^0$	(10)	1.00 (1+4[a])	1.23±1.20 (4+1[a])	[4–6]
	$^2P-^2D^0$	(14)	0.36±0.10 (6)	0.85±0.22 (6)	[4–6, 8]
	$^2P-^2P^0$	(15)		0.45±0.14 (6+3[a])	[4–6]
	$^2P-^2S^0$	(17)		0.84±0.27 (4)	[4–6]
$4s'-4p'$	$^2D-^2F^0$	(31)		1.11±0.11 (5)	[4–6]
$4p-4d$	$^4P^0-^4D$	(44)		1.66±0.09 (4)	[6]
	$^4D^0-^4D$	(54)	0.75±0.09 (9)	1.44±0.18 (9)	[6]
	$^4D^0-^4P$	(57)		1.19±0.12 (4)	[6]
	$^2P^0-^2P$	(83)	0.59±0.06 (3)	0.83±0.09 (3)	[6]
	$^4S^0-^4P$	(90)	0.91±0.04 (3)	1.28±0.06 (3)	[6]
$4p-5s$	$^4P^0-^4P$	(42)	0.98±0.12 (6)	1.14±0.14 (6)	[6]

[a] Theory predicts the opposite sign.

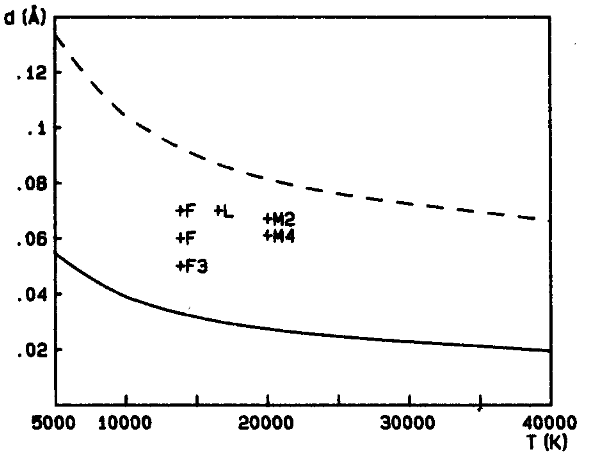

Fig. 1. Stark shifts for ArII $3d^4D-4p^4P^0$ multiplet. Theoretical curves: — — — ref. [12], ——— present results. Experimental points: F - Ref. [4], L - [5], M - [6], J - [8], C - [9], S - [11]. Numbers of line shifts with the same experimental values are also indicated

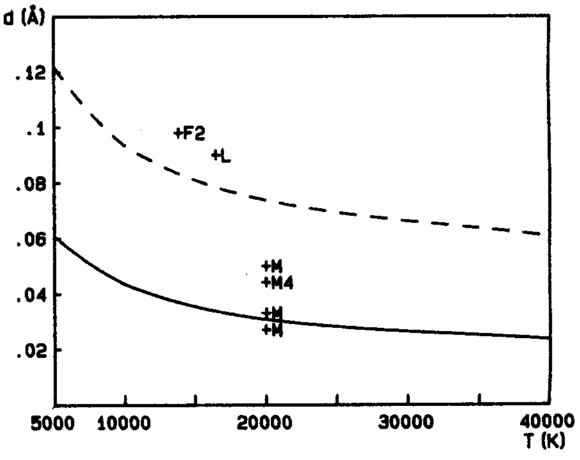

Fig. 2. Stark shifts for ArII $3d^4D-4p^4D^0$ multiplet. Notation is the same as in Fig. 1

and multiplets where $j\ell$ coupling perturbing levels play an important role (4f levels from $j\ell$ coupling scheme strongly influence Stark shifts of all multiplets from $4p4d$ and $4p'-4d'$ transition arrays). These multiplets are approximately treated with Coulomb approximation matrix elements and with appropriate angular Q—factors, according to e.g. Sobel'man [50]. Present results show that this is a reliable approximation for ArII lines. Furthermore, theoretical line shifts for such multiplets show practically the same average accuracy as in the case of pure LS coupling multiplets.

Table 2 lists averaged d_m/d_{th} values for 16 ArII multiplets covered with more than one experiment or with more than 2 line shift measurements. MSE results are somewhat worse for transitions between low lying energy levels.

Stark shifts for representative multiplets with largest number of experimental results are displayed in Figs. 1–5, showing similar agreement with experiments of MSE and semiclassical results. Temperature dependances of the Stark shifts are difficult to examine because of the actual uncertainty of experimental data that can be estimated as 50% according to [2, 3] for all experiments considered, except [4] with somewhat higher accuracy, and because of the fact that all measurements are performed in temperature

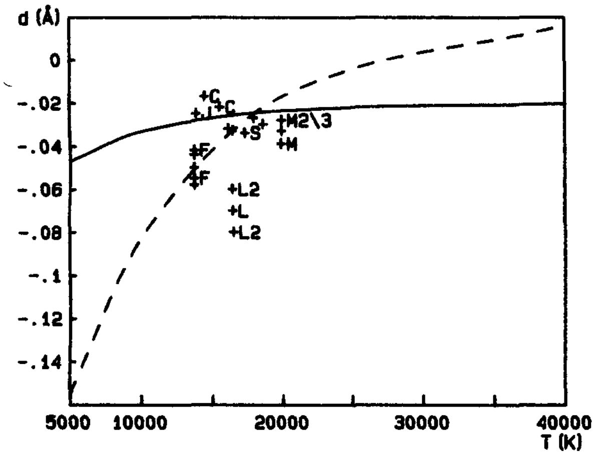

Fig. 3. Stark shifts for ArII $4s^4P-4p^4D^0$ multiplet. Notation is the same as in Fig. 1

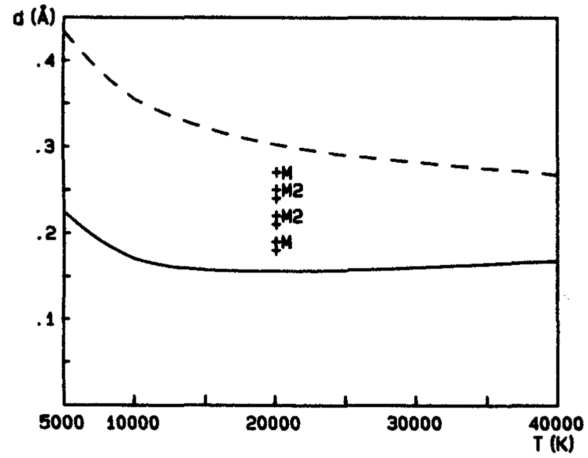

Fig. 4. Stark shifts for ArII $4p^4D^0-4d^4D$ multiplet. Notation is the same as in Fig. 1

range [10000, 20000] K. Extensive tables of MSE Stark widths and shifts as functions of T for 50 ArII multiplets will be published elsewhere [51].

Mean d_m/d_{th} values for individual experiments are shown in Table 3. One can see that with the exception of the experiment [5], the d_m/d_{th} ratio for the MSE theory varies between 0.72 and 1.53, i.e. it is approximately within ±50% limit. Moreover, for the experiment [5] where d_m/d_{th} for MSE calculation is 1.92, this ratio is the largest (1.54) for the semiclassical calculations also. If one averages averaged d_m/d_{th} values for individual experiments, mean d_m/d_{th} ratio is 1.26 ±0.34 for MSE and 1.02±0.34 for semiclassical theory.

On the basis of the results presented in [1] and in present paper, the MSE approach might be treated in the case of line shifts also as an useful method for simple and fast estimation of Stark broadening parameters with good average accuracy.

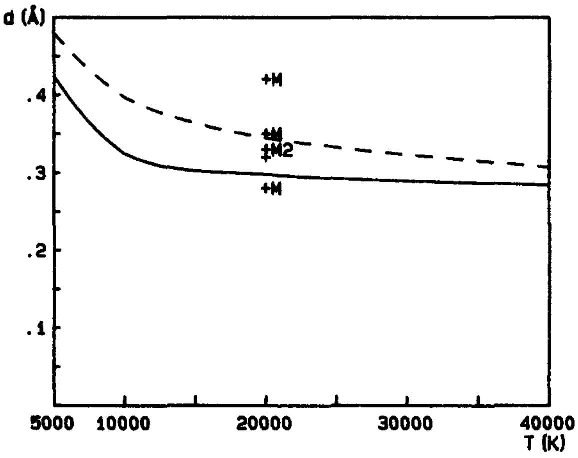

Fig. 5. Stark shifts for ArII $4p^4P^0-5s^4P$ multiplet. Notation is the same as in Fig. 1

Table 3. Mean ratios of measured to theoretical ArII Stark shifts for all experiments considered. Notation is the same as in Table 2

Experiment [Ref. No.]	SC	MSE
[4]	0.94±0.33 (16+2[a])	1.35±0.74 (25)
[5]	1.54±0.62 (15)	1.92±0.81 (16+6[a])
[6]	0.96±0.50 (47+2[a])	1.53±1.40 (106+1[a])
[7]	1.02±0.10 (2)	1.38±0.06 (2)
[8]	0.80±0.40 (4)	1.12±0.37 (4)
[9]	0.46±0.10 (2)	0.72±0.10 (2)
[10]		1.00±0.00 (2)
[11]	1.44±0.26 (12)	1.10±0.14 (12)
Mean	1.02±0.34	1.26±0.34

[a] Theory predicts the opposite sign

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Note added in proof. Recently, Djeniže et al. (Djeniže, S., Malešević, M., Srećković, A., Milosavljević, M., Purić, J.: J. Quant. Spectrosc. Radiat. Transfer (1989) (in press) have been measured Stark widths and shifts of 25 ArII lines in a linear pinch discharge. We found mean measured to theoretical (MSE) Stark shift ratio for 21 line shifts from this experiment to be 0.95 ± 0.48 with one result with opposite sign of the shift and the result for mult. 32 excluded. Mean d_m/d_{th} of semiclassical results [12] for 9 line shifts is 0.56 ± 0.23. Our averaged d_m/d_{th} values for all measurements became now 1.33 (MSE) and 1.02 (SC), and in the case of averaged means for individual experiments we now obtained 1.23 (MSE) and 0.96 (SC) with standard deviations in both cases practically unchanged. We wish to thank Prof. Purić for making results of this new experiment available in advance of publication.