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MODIFIED SEMIEMPIRICAL FORMULA FOR THE ELECTRON-IMPACT WIDTH OF IONIZED ATOM LINES: THEORY AND APPLICATIONS

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1. Introduction

In 1968, Griem [1] suggested a simple semiempirical impact approximation based on Baranger's [2] original formulation, together with the use of an effective Gaunt-factor approximation proposed by Seaton [3] and Van Regemorter [4]. For singly ionized atoms, this semiempirical formula agrees on the average within ± 50% with experiments [5]. For multiply ionized atoms, the agreement becomes worse and few attempts have been made to extend the applicability of this approach to higher ionisation stages [6-9]. This extension was done by adjustments of the effective Gaunt factors and by taking into account also the complexities of particular atomic structures (deviations from LS coupling, configuration mixing and optically forbidden transitions. Some limitations of these attempts [6-9] have been discussed recently by Dimitrijević and Konjević [10].

In this paper a modification of the semiempirical formula is reported and numerous theoretical calculations of line widths of ionized atoms are presented. The results of comparisons with other theoretical approaches and experiments are also given.

2. Theory

Within the impact approximation, Baranger [2] derived a quantum-mechanical expression for the width of an isolated ion line:

$$W = N\{v\,[\sum \sigma_{i'i} + \sum_{f'} \sigma_{f'f}]\}_{av} + W_{e\ell}\quad, \qquad (1)$$

where W is the full half-width (FWHM) in units of angular frequency and N is the electron concentration. The symbols $\sigma_{i'i}$ and $\sigma_{f'f}$ represent the inelastic cross sections for collisional transitions to i´, f´ from initial (i) and final (f) levels, respectively, of the optical transition. $W_{e\ell}$ is the line width induced by elastic collisions. The averaging in Eq. (1) has to be performed over the electron velocity (v) distribution.

Within the framework of the dipole approximation, one may use Bethe´s relation [11]

$$\sigma_{j'j} = \frac{8\pi}{3}\lambda^2 \vec{R}^2_{j'j} \frac{\pi}{\sqrt{3}} g \qquad (2)$$

to evaluate inelastic cross sections. In this expression $\lambda = \hbar/mv$ is the reduced de Broglie wavelength of an electron and $\vec{R}^2_{j'j}$ (in units of the Bohr radius a_o) is the square of the coordinate operator matrix element summed over all components of the operator, the magnetic substates of total angular momentum J´, and averaged over the magnetic substates of J.

For higher electron temperatures, Griem [1] assumed that the contribution of elastic collisions to the line width [cf.Eq. (1)] can be neglected. The same author [1] made an attempt to take elastic collisions into account in the low temperature limit by using the threshold value of the inelastic cross section below the threshold. The Stark line width can then be calculated from the well known semiempirical formula [1]

$$W = N \frac{8\pi}{3} \frac{\hbar^2}{m^2} \left(\frac{2m}{\pi kT}\right)^{1/2} \frac{\pi}{\sqrt{3}} \left[\sum_{i'} \vec{R}^2_{i'i}\, g\left(\frac{E}{\Delta E_{i'i}}\right) + \sum_{f'} \vec{R}^2_{f'f}\, g\left(\frac{E}{\Delta E_{f'f}}\right)\right] \qquad (3)$$

Here, $E = 3kT/2$ is the energy of the perturbing electron and $\Delta E_{j'j} = [E_{j'} - E_j]$ is the energy difference between levels j and j'; $g(x) = 0.20$ for $x \leq 2$ and $g(x) = 0.24, 0.33, 0.56, 0.98$, and 1.33 for $x = 3, 5, 10, 30$, and 100.

If the nearest perturbing level in Eq. (3) is so far from E_i or E_f that the condition $E/\Delta E_{j'j} \leq 2$ is satisfied, g becomes a costant [1]. Then, the summation in Eq. (3) can be performed straightforwardly leading to considerable simplification of the relation. The line width (FWHM) in Å units then becomes

$$W(\text{Å}) = 0.4430 \cdot 10^{-8} \frac{\lambda^2(\text{cm})\, N(\text{cm}^{-3})}{T^{1/2}} (\vec{R}^2_{ii} + \vec{R}^2_{ff}), \qquad (4)$$

$$\vec{R}^2_{jj} = \sum_{j'} \vec{R}^2_{j'j} \simeq \frac{1}{2}\left(\frac{n_j}{Z}\right)^2 [5n_j^2 + 1 - 3\ell_j(\ell_j + 1)], \qquad (5)$$

where n_j is the effective principal and ℓ_j the orbital angular momentum quantum number, while $(Z-1)$ is the ionic charge.

As we have pointed out previously, the semiempirical relation agrees on the average within ±50% with experimenal data for singly-ionized atoms. However some authors (see e.g. Kobzev [6]) already pointed out that the constant threshold value of the Gaunt factor for all kinds of transitions was not always an adequate choice. On the other hand Griem [5] suggested that the unmodified semiempirical formula can be used for multiply--ionized atoms as well, but with an accuracy of ±100 %.However, the comparison with the experimental values of line widths of doubly- and triply-ionized atoms [6-9, 12-15] shows that the theoretical results are systematically lower. This observation is an indication that the threshold value of 0.2 for the Gaunt factor is rather small for higher ionization stages.

For the transitions with the principal quantum number n unchanged, Kobzev [16] suggested an empirical value of $g = 0.9 - 1/Z$ at threshold. We have adopted this suggestion. Therefore, in Eq. (3), the contribution of the collisional transitions with $\Delta n = 0$ is treated separately. For higher electronic energies, the Gaunt factor is calculated from the following equation:

$$\tilde{g}(x) = 0.7 - 1.1/Z + g(x). \tag{6}$$

If one uses Eq. (3) to calculate Stark line widths, a lack of atomic data causes difficulties in the evaluation of necessary matrix elements. These difficulties are especially serious for multiply-ionized atoms for which data on higher perturbing levels are sometimes completely missing in the literature. To overcome this problem, we have separated the transitions with $\Delta n = 0$. Also, the LS coupling approximation is assumed. In this case, only two matrix elements are calculated: one for the transition array $\ell \to \ell+1$ ($R^2_{\ell,\ell+1}$) and the other for $\ell \to \ell-1$ ($R^2_{\ell,\ell-1}$). The same technique has been used by Griem [5] for semiclassical calculations of multiply charged ion line widths.

Equation (3) becomes now

$$W = N \frac{8\pi}{3} \frac{\hbar^2}{m^2} \left(\frac{2m}{\pi kT}\right)^{1/2} \frac{\pi}{\sqrt{3}} \Bigg[\vec{R}^2_{\ell_i,\ell_i+1} \tilde{g}\left(\frac{E}{\Delta E_{\ell_i,\ell_i+1}}\right) + \vec{R}^2_{\ell_i,\ell_i-1} \tilde{g}\left(\frac{E}{\Delta E_{\ell_i,\ell_i-1}}\right) + \vec{R}^2_{\ell_f,\ell_f+1} \tilde{g}\left(\frac{E}{\Delta E_{\ell_f,\ell_f+1}}\right) + \vec{R}^2_{\ell_f,\ell_f-1} \tilde{g}\left(\frac{E}{\Delta E_{\ell_f,\ell_f-1}}\right) + \sum_{i'} (\vec{R}^2_{ii'})_{\Delta n \neq 0} \cdot g\left(\frac{3kTn_i^3}{4Z^2E_H}\right) + \sum_{f'} (\vec{R}^2_{ff'})_{\Delta n \neq 0}\, g\left(\frac{3kTn_f^3}{4Z^2E_H}\right) \Bigg], \tag{7}$$

$$\vec{R}^2_{\ell,\ell'} \simeq \left(\frac{3n}{2Z}\right)^2 \frac{\max(\ell,\ell')}{2\ell+1} \left[n^2 - \max^2(\ell,\ell')\right] \phi^2, \tag{8}$$

$$\sum_{j'} (\vec{R}^2_{jj'})_{\Delta n \neq 0} \simeq \left(\frac{3n_j}{2Z}\right)^2 \frac{1}{9} \left(n_j^2+3\ell_j^2+3\ell_j+11\right). \tag{9}$$

For the inelastic part in Eq. (7) the nearest perturbing level is estimated from

$$\Delta E_{n,n+1} \approx 2Z^2 E_H/n^3 \quad .$$

At high temperatures, say $3kT/2\Delta E > 50$, all Gaunt factors in Eq. (7) are calculated in accordance with the GBKO high temperature limit [17], viz.

$$\tilde{g}_{j'j} = g_{j'j} = \frac{\sqrt{3}}{\pi} \left[\frac{1}{2} + \ell n \left(\frac{2Z\ kT}{n_j^2\ \Delta E_{j'j}}\right)\right]. \tag{10}$$

3. Results and comparisons with experiments

In order to estimate the accuracy of the theoretical results a detailed comparison with available experimental data for doubly and triply ionized atoms [12-14, 33-37] has been performed in Ref. 18;a summary is given in Table 1. A comparison has also been made with experiments for singly ionized atom lines and three typical examples are given in Fig. 1.

Table 1. Average ratios of measured and calculated linewidths for various doubly and triply ionized atoms

Element	T_e [K]	W_m/W_{SEM}	W_m/W_{SE}
CIII	60000	1.29	1.21
NIII	24300	0.92	1.71
OIII	25400	1.05	1.90
SiIII	25600	0.67	1.08
SIII	28500	1.16	1.65
ClIII	24200	1.01	1.68
AIII	21100	0.99	1.57
average ratio:		1.06±0.31	1.53±0.46

Element	T_e [K]	W_m/W_{SEM}	W_m/W_{SE}
CIV	60000	1.50	2.57
SiIV	25600	0.66	1.15
SIV	28500	0.80	1.65
AIV	21500	0.76	1.24
average ratio:		0.91±0.42	1.56±0.85

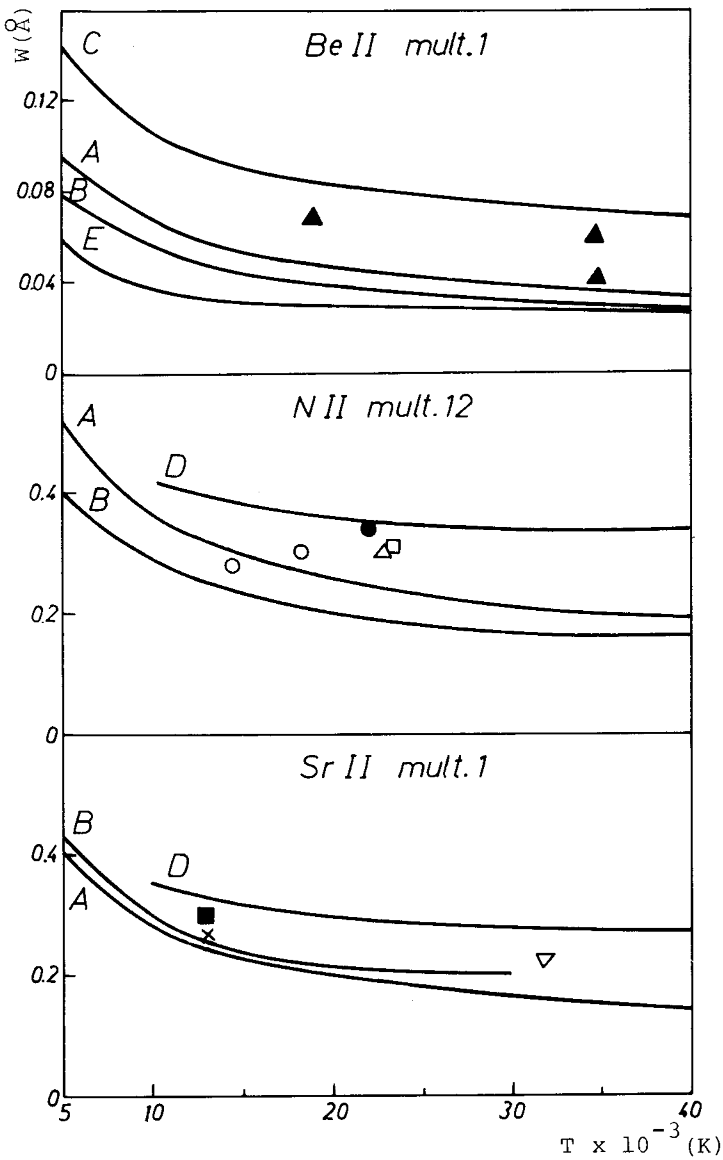

FIG.1. Measured and calculated full halfwidths for singly ionized atoms, normalized to an electron density of $1\times10^{17}cm^{-3}$, as a function of electron temperature. Curves: A:W_{SEM}; B:W_{SE}; C:W_{SC}-Jones et al [38] ; D:W_{SC}-our calculations; E:quantum mechanical results with exchange by Sanchez et al [39]. Experimental points: ▲-Sanchez et al [39] ; ●-Berg et al [40] ; △-Jalufka and Craig [41] ; o-Konjević et al [42] ; □-Popović et al [43] ; ■-Fleurier et al [44] ; ▽-Hadžiomerspahić et al [45] ; Theoretical points: x - Fleurier et al [44]

The results of numerous theoretical calculations of the electron impact line widths of prominent, isolated lines of BeIII through AIII and BIV through AIV are given in Table 2, where under W_{SEM} results are given obtained from eqs. (7) - (10), W_{SE}: eqs. (4) and (5). For the sake of comparison the same table contains the results W_G of a semiclassical formula (see Ref. 5, eq. 526 on p. 279, and the details of the calculations in Ref. 18) and its modified form [18], W_{GM}.

It is not necessary to discuss here uncertainties from the approximations involved in our calculations since the criteria for their application are given in detail elsewhere (see e.g. Ref. 5).

Additional errors which are not inherent to the theoretical approaches described above are related to the calculation of matrix elements and the lack of atomic data.

For evaluation of the radial integrals, the tables of Bates and Damgaard [14, 20] have been used. The cases when an atomic state with equivalent electrons is the principal one are avoided. If such a state is the perturbing one, corresponding coefficients of fractional parentage [21] are included whenever possible.

Data for atomic energy levels were taken from references 22 - 28. Some additional information is available for SIII [29], NaIII [30, 31] and PIII [32]. The results for multiplets 4UV, 5UV, 2 and 6 of AIV are probably less accurate since the data for the 4d level are missing.

TABLE 2. This table lists electron impact full half widths of isolated lines from doubly and triply ionized atoms from beryllium through argon at an electron density of $1x10^{17}$ cm^{-3} and electron temperatures T from 10.000 to 80.000K. Transition and averaged wavelength for the multiplet (in angström units) are also given. Under W_{SEM} and W_{SE} are given semiempirical results obtained from eqs. (7-10) and (4-5) respectively. W_{GM} are semiclassical results obtained from eqs.(11-15) in Ref. 18 (with 1.4 instead of 5-(4.5/Z) on the right-hand-side of eq.(12)in Ref. 18), and W_G are the results from eqs. (11-15) in Ref. 18. The value for $3kT/2\Delta E$ represents the ratio of the thermal electron energy at 10.000K to the energy difference to the nearest perturbing level.

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
BE III $2s\,^1S-2p\,^1P^o$	10000	0.227	0.128	0.197	0.282
	20000	0.160	0.904-1	0.155	0.210
λ= 6141.0	30000	0.131	0.738-1	0.139	0.181
3kT/2ΔE=0.64	40000	0.117	0.711-1	0.131	0.165
	80000	0.947-1		0.117	0.136
BE III $2s\,^3S-2p\,^3P^o$	10000	0.701-1	0.402-1	0.617-1	0.874-1
	20000	0.496.1	0.284-1	0.471-1	0.644-1
λ= 3721.8	30000	0.405-1	0.232-1	0.414-1	0.548-1
3kT/2ΔE=0.39	40000	0.351-1	0.201-1	0.383-1	0.493-1
	80000	0.263-1	0.175-1	0.333-1	0.399-1
B III $2s\,^2S-2p\,^2P^o$	10000	0.191-1	0.115-1	0.176-1	0.244-1
	20000	0.135-1	0.815-2	0.131-1	0.178-1
λ= 2066.3	30000	0.110-1	0.665-2	0.113-1	0.150-1
3kT/2ΔE=0.22	40000	0.953-2	0.576-2	0.103-1	0.134-1
	80000	0.674-2	0.408-2	0.867-2	0.106-1

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
B III $4p\,^2P^o-5d\,^2D$	10000	9.88		6.72	7.74
	20000	8.29		6.08	6.62
λ = 4243.6	30000	7.44		5.68	6.04
$3kT/2\Delta E$ = 390.	40000	6.83		5.39	5.66
	80000	5.81		4.66	4.79
B III $4d\,^2D-5f\,^2F^o$	10000	12.2		7.62	8.15
	20000	9.85		6.76	7.00
λ = 4487.5	30000	8.66		6.24	6.38
$3kT/2\Delta E$ = 1000.	40000	7.90		5.86	5.96
	80000	6.39		4.96	5.01
B IV $2s\,^1S-2p\,^1P^o$	10000	0.396-1	0.200-1	0.367-1	0.481-1
	20000	0.280-1	0.141-1	0.277-1	0.353-1
λ = 4499.4	30000	0.228-1	0.115-1	0.240-1	0.299-1
$3kT/2\Delta E$ = 0.46	40000	0.198-1	0.999-2	0.220-1	0.268-1
	80000	0.152-1		0.187-1	0.214-1
B IV $2s\,^3S-2p\,^3P^o$	10000	0.269-1	0.136-1	0.201-1	0.316-1
	20000	0.190-1	0.958-2	0.150-1	0.228-1
λ = 2823.4	30000	0.155-1	0.782-2	0.129-1	0.191-1
$3kT/2\Delta E$ = 0.29	40000	0.134-1	0.678-2	0.117-1	0.169-1
	80000	0.966-2	0.513-2	0.986-2	0.131-1
C III $2p\,^3P^o-3s\,^3S$	10000	0.344-2	0.184-2	0.314-2	0.463-2
mult. 5UV	20000	0.243-2	0.130-2	0.244-2	0.344-2
λ = 538.2	30000	0.198-2	0.106-2	0.218-2	0.295-2
$3kT/2\Delta E$ = 0.48	40000	0.172-2	0.920-3	0.203-2	0.267-2
	80000	0.139-2		0.180-2	0.218-2
C III $3s\,^3S-3p\,^3P^o$	10000	0.523	0.263	0.410	0.642
mult. 1	20000	0.370	0.187	0.329	0.482
λ = 4648.8	30000	0.308	0.169	0.299	0.416
$3kT/2\Delta E$ = 1.0	40000	0.274		0.283	0.379
	80000	0.229		0.256	0.313

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
C III $3s'^1P^o-3p'^1D$	10000	0.486	0.230	0.377	0.589
mult. 7	20000	0.346	0.167	0.314	0.451
λ = 4326.0	30000	0.300		0.292	0.394
3kT/2ΔE = 1.1	40000	0.280		0.281	0.363
	80000	0.249		0.260	0.307
C III $3p^1P^o-3d^1D$	10000	0.736	0.410	0.716	0.991
mult. 2	20000	0.521	0.290	0.564	0.745
λ = 5696.0	30000	0.430	0.253	0.506	0.644
3kT/2ΔE = 0.89	40000	0.384		0.474	0.588
	80000	0.315		0.422	0.489
C III $3p^1P^o-4d^1D$	10000	0.172		0.180	0.233
	20000	0.139		0.158	0.189
λ = 1531.8	30000	0.124		0.148	0.170
3kT/2ΔE = 6.9	40000	0.115		0.142	0.159
	80000	0.103		0.128	0.137
C III $4p^3P^o-5d^3D$	10000	3.16		2.83	3.80
mult. 10	20000	2.77		2.54	3.10
λ = 3609.3	30000	2.62		2.40	2.80
3kT/2ΔE = 8.3	40000	2.49		2.31	2.62
	80000	2.16		2.08	2.24
C IV $2s^2S-2p^2P^o$	10000	0.728-2	0.383-2	0.570-2	0.873-2
mult.1UV	20000	0.515-2	0.271-2	0.417-2	0.627-2
λ = 1549.1	30000	0.421-2	0.221-2	0.353-2	0.522-2
3kT/2ΔE = 0.16	40000	0.364-2	0.192-2	0.318-2	0.460-2
	80000	0.258-2	0.135-2	0.257-2	0.350-2
C IV $2s^2S-4p^2P^o$	10000	0.295-2		0.232-2	0.354-2
mult. 3UV	20000	0.246-2		0.202-2	0.277-2
λ = 244.9	30000	0.220-2		0.190-2	0.245-2
3kT/2ΔE = 5.2	40000	0.207-2		0.183-2	0.227-2
	80000	0.169-2		0.169-2	0.193-2

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
C IV $2p^2P^o-3s^2S$	10000	0.227-2	0.949-3	0.164-2	0.278-2
mult. 6UV	20000	0.161.2	0.671-3	0.128-2	0.204-2
λ = 419.6	30000	0.131-2	0.548-3	0.114-2	0.174-2
$3kT/2\Delta E$ = 0.61	40000	0.116-2	0.509-3	0.107-2	0.156-2
	80000	0.936-3		0.954-3	0.125-2
C IV $2p^2P^o-4d^2D$	10000	0.570-2		0.449-2	0.536-2
mult. 9UV	20000	0.450-2		0.397-2	0.445-2
λ = 289.2	30000	0.390-2		0.370-2	0.403-2
$3kT/2\Delta E$ = 110.	40000	0.352-2		0.352-2	0.377-2
	80000	0.272-2		0.309-2	0.321-2
C IV $3s^2S-3p^2P^o$	10000	0.776	0.320	0.495	0.880
mult. 1	20000	0.571		0.402	0.656
λ = 5804.9	30000	0.484		0.369	0.564
$3kT/2\Delta E$ = 2.2	40000	0.440		0.352	0.511
	80000	0.368		0.325	0.419
C IV $4d^2D-5f^2F^o$	10000	2.13		1.24	1.38
mult. 14UV	20000	1.73		1.12	1.18
λ = 2524.4	30000	1.52		1.04	1.08
$3kT/2\Delta E$ = 1000.	40000	1.38		0.983	1.01
	80000	1.10		0.847	0.860
N III $2p^2P^o-3s^2S$	10000	0.202-2	0.108-2	0.185-2	0.272-2
mult. 4 UV	20000	0.143-2	0.801-3	0.143-2	0.201-2
λ = 452.1	30000	0.116-2		0.127-2	0.172-2
$3kT/2\Delta E$ = 1.1	40000	0.101-2		0.118-2	0.155-2
	80000	0.783-3		0.104-2	0.127-2
N III $3s^2S-3p^2P^o$	10000	0.333	0.173	0.261	0.408
mult. 1	20000	0.236	0.125	0.205	0.304
λ = 4097.3	30000	0.192		0.183	0.260
$3kT/2\Delta E$ = 1.1	40000	0.167		0.172	0.235
	80000	0.131		0.154	0.192

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
N III $3s^4P^o-3p^4P$	10000	0.236	0.121	0.188	0.292
mult. 5	20000	0.167	0.853-1	0.149	0.218
λ = 3367.3	30000	0.137	0.730-1	0.134	0.188
3kT/2ΔE = 0.81	40000	0.121		0.127	0.170
	80000	0.966-1		0.114	0.140
N III $3p^2P^o-3d^2D$	10000	0.415	0.236	0.413	0.565
mult. 2	20000	0.294	0.167	0.319	0.421
λ = 4640.6	30000	0.240	0.136	0.283	0.362
3kT/2ΔE = 0.48	40000	0.208	0.118	0.263	0.328
	80000	0.163		0.230	0.270
N IV $3s^3S-3p^3P^o$	10000	0.213	0.906-1	0.135	0.242
mult. 1	20000	0.151	0.641-1	0.105	0.177
λ = 3480.8	30000	0.124	0.535-1	0.929-1	0.150
3kT/2ΔE = 0.74	40000	0.108	0.499-1	0.869-1	0.134
	80000	0.837-1		0.776-1	0.107
N IV $3p^3P^o-3d^3D$	10000	0.735	0.353	0.588	0.904
mult. 4	20000	0.520	0.250	0.454	0.666
λ = 7117.0	30000	0.427	0.213	0.401	0.566
3kT/2ΔE = 0.74	40000	0.379	0.211	0.373	0.509
	80000	0.304		0.329	0.411
O III $3s^3P^o-3p^3D$	10000	0.230	0.122	0.183	0.283
mult. 2	20000	0.163	0.863-1	0.142	0.209
λ = 3762.3	30000	0.133	0.705-1	0.126	0.179
3kT/2ΔE = 0.63	40000	0.115	0.641-1	0.118	0.161
	80000	0.866-1		0.104	0.131
O III $3s^3P^o-3p^3S$	10000	0.185	0.981-1	0.148	0.229
mult. 3	20000	0.131	0.694-1	0.115	0.169
λ = 3326.6	30000	0.107	0.566-1	0.102	0.144
3kT/2ΔE = 0.63	40000	0.925-1	0.514-1	0.952-1	0.130
	80000	0.693-1		0.844-1	0.106

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
O III $3s^3P^o-3p^3P$	10000	0.158	0.839-1	0.127	0.197
mult. 4	20000	0.112	0.594-1	0.985-1	0.146
λ = 3041.5	30000	0.914-1	0.485-1	0.879-1	0.124
3kT/2ΔE = 0.63	40000	0.792-1	0.440-1	0.821-1	0.112
	80000	0.595-1		0.728-1	0.912-1
O III $3s^1P^o-3p^1D$	10000	0.171	0.877-1	0.137	0.213
mult. 6	20000	0.121	0.620-1	0.109	0.159
λ = 2983.8	30000	0.989-1	0.506-1	0.978-1	0.136
3kT/2ΔE = 0.58	40000	0.865-1	0.466-1	0.921-1	0.124
	80000	0.673-1		0.828-1	0.102
O III $3s^5P-3p^5D^o$	10000	0.223	0.118	0.177	0.275
mult. 21	20000	0.158	0.836-1	0.138	0.203
λ = 3706.1	30000	0.129	0.683-1	0.122	0.174
3kT/2ΔE = 0.39	40000	0.112	0.591-1	0.114	0.157
	80000	0.841-1	0.513-1	0.101	0.127
O III $3s^5P-3p^5S^o$	10000	0.126	0.673-1	0.103	0.158
mult. 22UV	20000	0.891-1	0.476-1	0.796-1	0.117
λ = 2678.2	30000	0.728-1	0.389-1	0.708-1	0.997-1
3kT/2ΔE = 0.46	40000	0.630-1	0.337-1	0.660-1	0.901-1
	80000	0.473-1		0.585-1	0.732-1
O III $3p^3P-3d^3D^o$	10000	0.245	0.144	0.252	0.339
mult. 14	20000	0.173	0.102	0.193	0.252
λ = 3712.5	30000	0.141	0.830-1	0.169	0.216
3kT/2ΔE = 0.39	40000	0.122	0.719-1	0.157	0.195
	80000	0.907-1	0.625-1	0.136	0.160
O III $3p^5D^o-3d^5F$	10000	0.196	0.113	0.204	0.273
mult. 25	20000	0.139	0.800-1	0.156	0.202
λ = 3453.0	30000	0.113	0.653-1	0.137	0.173
3kT/2ΔE = 0.39	40000	0.982-1	0.566-1	0.126	0.157
	80000	0.727-1	0.480-1	0.109	0.128

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
O III $3d\,^3P^o-4p\,^3S$	10000	0.321	0.171	0.300	0.437
mult. 20UV	20000	0.227	0.121	0.240	0.330
λ = 2601.6	30000	0.188	0.112	0.216	0.285
$3kT/2\Delta E$ = 0.95	40000	0.168		0.203	0.260
	80000	0.134		0.181	0.215
O III $3d\,^1F^o-4p\,^1D$	10000	0.356	0.179	0.333	0.483
mult. 21UV	20000	0.262	0.148	0.272	0.369
λ = 2558.1	30000	0.227		0.249	0.322
$3kT/2\Delta E$ = 1.5	40000	0.210		0.236	0.295
	80000	0.175		0.213	0.247
O IV $2p\,^2P^o-3s\,^2S$	10000	0.596-3	0.270-3	0.453-3	0.746-3
mult. 4UV	20000	0.421-3	0.191-3	0.342-3	0.543-3
λ = 279.8	30000	0.344-3	0.156-3	0.297-3	0.456-3
$3kT/2\Delta E$ = 0.32	40000	0.298-3	0.135-3	0.273-3	0.406-3
	80000	0.217-3	0.105-3	0.235-3	0.319-3
O IV $2p\,^2P^o-3d\,^2D$	10000	0.330-3	0.195-3	0.451-3	0.556-3
mult. 5UV	20000	0.233-3	0.138-3	0.336-3	0.408-3
λ = 238.5	30000	0.190.3	0.112-3	0.288-3	0.345-3
$3kT/2\Delta E$ = 0.36	40000	0.165-3	0.973-4	0.262-3	0.310-3
	80000	0.117-3	0.792-4	0.219-3	0.249-3
O IV $3s\,^4P^o-3p\,^4D$	10000	0.168	0.721-1	0.106	0.190
mult. 3	20000	0.119	0.510-1	0.812-1	0.139
λ = 3374.3	30000	0.968-1	0.416-1	0.714-1	0.117
$3kT/2\Delta E$ = 0.39	40000	0.838-1	0.360-1	0.663-1	0.104
	80000	0.622-1	0.294-1	0.583-1	0.820-1
O IV $3p\,^4P-3d\,^4D^o$	10000	0.310	0.152	0.252	0.385
mult. 9	20000	0.219	0.107	0.192	0.282
λ = 4792.5	30000	0.179	0.875-1	0.167	0.238
$3kT/2\Delta E$ = 0,50	40000	0.155	0.758-1	0.154	0.213
	80000	0.119		0.133	0.170

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
O IV $3p^2D-3d^2D^o$	10000	0.400	0.193	0.323	0.495
mult. 11	20000	0.283	0.137	0.246	0.363
λ = 5339.5	30000	0.231	0.112	0.216	0.307
3kT/2ΔE = 0.56	40000	0.202	0.101	0.200	0.276
	80000	0.156		0.174	0.221
F III $3s^4P_6-3p^4P^o_6$	10000	0.119	0.660-1	0.975-1	0.148
	20000	0.839-1	0.467-1	0.748-1	0.109
λ = 2916.3	30000	0.685-1	0.381-1	0.659-1	0.930-1
3kT/2ΔE = 0.33	40000	0.593-1	0.330-1	0.612-1	0.837-1
	80000	0.430-1	0.258-1	0.535-1	0.676-1
F III $3s^4P-3p^4D^o$	10000	0.134	0.743-1	0.110	0.167
mult. 1	20000	0.949-1	0.525-1	0.842-1	0.123
λ = 3124.4	30000	0.775-1	0.429-1	0.742-1	0.105
3kT/2ΔE = 0.33	40000	0.671-1	0.371-1	0.689-1	0.944-1
	80000	0.489-1	0.294-1	0.603-1	0.761-1
F III $3s^2P_4-3p^2P^o_4$	10000	0.130	0.684-1	0.105	0.162
	20000	0.918-1	0.483-1	0.822-1	0.120
λ = 2811.4	30000	0.750-1	0.395-1	0.733-1	0.103
3kT/2ΔE = 0.53	40000	0.651-1	0.346-1	0.686-1	0.929-1
	80000	0.488-1		0.611-1	0.759-1
F III $3s^2P-3p^2D^o$	10000	0.160	0.843-1	0.129	0.198
mult. 2	20000	0.113	0.596-1	0.101	0.147
λ = 3176.9	30000	0.924-1	0.487-1	0.897-1	0.126
3kT/2ΔE = 0.53	40000	0.801-1	0.426-1	0.840-1	0.114
	80000	0.603-1		0.748-1	0.929-1
NE III $3s^3S^o-3p^3P$	10000	0.965-1	0.540-1	0.800-1	0.121
mult. 12UV	20000	0.683-1	0.382-1	0.612-1	0.892-1
λ = 2678.2	30000	0.557-1	0.312-1	0.538-1	0.758-1
3kT/2ΔE = 0.32	40000	0.483-1	0.270-1	0.498-1	0.682-1
	80000	0.348-1	0.200-1	0.434-1	0.549-1

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
NE III $3s'\,^3D^o-3p'\,^3F$	10000	0.832-1	0.474-1	0.697-1	0.105
	20000	0.588-1	0.335-1	0.532-1	0.771-1
λ = 2612.4	30000	0.480-1	0.274-1	0.466-1	0.654-1
$3kT/2\Delta E$ = 0.29	40000	0.416-1	0.237-1	0.431-1	0.588-1
	80000	0.297-1	0.176-1	0.374-1	0.472-1
NE III $3p\,^5P_7-3d\,^5D^o_9$	10000	0.685-1	0.452-1	0.803-1	0.103
	20000	0.484-1	0.319-1	0.606-1	0.760-1
λ = 2163.8	30000	0.395-1	0.261-1	0.527-1	0.649-1
$3kT/2\Delta E$ = 0.27	40000	0.342-1	0.226-1	0.483-1	0.586-1
	80000	0.243-1	0.162-1	0.412-1	0.477-1
NE IV $3s\,^4P-3p\,^4D^o$	10000	0.608-1	0.281-1	0.404-1	0.703-1
	20000	0.430-1	0.199-1	0.303-1	0.509-1
λ = 2361.5	30000	0.351-1	0.162-1	0.262-1	0.426-1
$3kT/2\Delta E$ = 0.25	40000	0.304-1	0.141-1	0.240-1	0.378-1
	80000	0.215-1	0.994-2	0.204-1	0.293-1
NE IV $3s'\,^2D-3p'\,^2F^o$	10000	0.588-1	0.270-1	0.390-1	0.679-1
	20000	0.416-1	0.191-1	0.292-1	0.492-1
λ = 2289.1	30000	0.339-1	0.156-1	0.253-1	0.412-1
$3kT/2\Delta E$ = 0.39	40000	0.294-1	0.135-1	0.231-1	0.366-1
	80000	0.208-1	0.106-1	0.197-1	0.284-1
NA III $3s\,^4P-3p\,^4P^o$	10000	0.667-1	0.390-1	0.570-1	0.846-1
	20000	0.472-1	0.276-1	0.432-1	0.621-1
λ = 2515.6	30000	0.385-1	0.225-1	0.377-1	0.526-1
$3kT/2\Delta E$ = 0.26	40000	0.333-1	0.195-1	0.348-1	0.472-1
	80000	0.237-1	0.141-1	0.300-1	0.378-1
NA III $3s\,^4P-3p\,^4D^o$	10000	0.545-1	0.319-1	0.469-1	0.695-1
	20000	0.385-1	0.226-1	0.355-1	0.510-1
λ = 2232.5	30000	0.315-1	0.184-1	0.310-1	0.432-1
$3kT/2\Delta E$ = 0.26	40000	0.272-1	0.159-1	0.286-1	0.388-1
	80000	0.193-1	0.114-1	0.246-1	0.311-1

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
NA III $3s\,^4P-3p\,^4S^o$	10000	0.441-1	0.260-1	0.384-1	0.568-1
	20000	0.311-1	0.184-1	0.291-1	0.417-1
λ = 1971.5	30000	0.254-1	0.150-1	0.254-1	0.353-1
$3kT/2\Delta E$ = 0.26	40000	0.220-1	0.130-1	0.234-1	0.317-1
	80000	0.156-1	0.928-2	0.201-1	0.254-1
NA III $3s\,^2P-3p\,^2D^o$	10000	0.689-1	0.408-1	0.591-1	0.879-1
	20000	0.487-1	0.289-1	0.449-1	0.645-1
λ = 2458.9	30000	0.398-1	0.236-1	0.392-1	0.547-1
$3kT/2\Delta E$ = 0.26	40000	0.345-1	0.204-1	0.361-1	0.491-1
	80000	0.244-1	0.146-1	0.311-1	0.393-1
NA III $3s\,^2P-3p\,^2P^o$	10000	0.593-1	0.351-1	0.512-1	0.760-1
	20000	0.419-1	0.248-1	0.388-1	0.558-1
λ = 2247.4	30000	0.342-1	0.203-1	0.339-1	0.473-1
$3kT/2\Delta E$ = 0.26	40000	0.296-1	0.176-1	0.312-1	0.424-1
	80000	0.210-1	0.125-1	0.269-1	0.340-1
MG IV $3s\,^4P-3p\,^4S^o$	10000	0.199-1	0.969-2	0.140-1	0.236-1
	20000	0.140-1	0.685-2	0.104-1	0.170-1
λ = 1477.8	30000	0.115-1	0.559-2	0.892-2	0.142-1
$3kT/2\Delta E$ = 0.20	40000	0.993-2	0.484-2	0.810-2	0.126-1
	80000	0.702-2	0.342-2	0.678-2	0.972-2
MG IV $3p\,^4S^o_4-3d\,^4P_6$	10000	0.238-1	0.133-1	0.230-1	0.324-1
	20000	0.169-1	0.941-2	0.170-1	0.236-1
λ = 1548.1	30000	0.138-1	0.768-2	0.145-1	0.198-1
$3kT/2\Delta E$ = 0.16	40000	0.119-1	0.665-2	0.132-1	0.176-1
	80000	0.843-2	0.470-2	0.109-1	0.138-1
AL III $3s\,^2S-3p\,^2P^o$	10000	0.303-1	0.193.1	0.277-1	0.398-1
mult. 1UV	20000	0.214-1	0.136-1	0.208-1	0.291-1
λ = 1857.4	30000	0.175-1	0.111-1	0.180-1	0.246-1
$3kT/2\Delta E$ = 0.19	40000	0.151-1	0.963-2	0.165-1	0.220-1
	80000	0.107-1	0.681-2	0.140-1	0.175-1

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
AL III $3s^2S-4p^2P^o$	10000	0.136-1	0.837-2	0.138-1	0.199-1
mult. 2UV	20000	0.964-2	0.592-2	0.107-1	0.148-1
λ = 696.0	30000	0.787-2	0.483-2	0.953-2	0.127-1
3kT/2ΔE = 0.60	40000	0.684-2	0.446-2	0.886-2	0.115-1
	80000	0.525-2		0.777-2	0.940-2
AL III $3s^2S-5p^2P^o$	10000	0.238-1	0.145-1	0.254-1	0.361-1
mult. 3UV	20000	0.169-1	0.115-1	0.204-1	0.274-1
λ = 560.4	30000	0.144-1		0.184-1	0.238-1
3kT/2ΔE = 1.3	40000	0.131-1		0.173-1	0.217-1
	80000	0.111-1		0.154-1	0.180-1
AL III $4s^2S-4p^2P^o$	10000	1.48	0.859	1.20	1.87
mult. 2	20000	1.04	0.607	0.951	1.40
λ = 5705.9	30000	0.852	0.496	0.856	1.20
3kT/2ΔE = 0.60	40000	0.751	0.462	0.805	1.09
	80000	0.616		0.720	0.895
AL III $4p^2P^o-4d^2D$	10000	1.45		1.37	1.90
mult. 3	20000	1.14		1.14	1.47
λ = 4523.2	30000	0.996		1.04	1.30
3kT/2ΔE = 5.7	40000	0.909		0.983	1.19
	80000	0.764		0.876	1.00
AL III $4f^2F^o-5d^2D$	10000	4.42		4.14	5.25
mult. 6	20000	3.77		3.60	4.25
λ = 4701.6	30000	3.38		3.35	3.82
3kT/2ΔE = 10.	40000	3.16		3.18	3.56
	80000	2.65		2.83	3.03
AL III $4d^2D-6f^2F^o$	10000	5.92		4.82	5.40
	20000	5.01		4.27	4.58
λ = 2762.8	30000	4.50		3.95	4.15
3kT/2ΔE = 320.	40000	4.20		3.72	3.87
	80000	3.53		3.18	3.25

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
SI III $3p^3P^o-4s^3S$	10000	0.175-1	0.109-1	0.165-1	0.242-1
mult. 6UV	20000	0.124-1	0.772-2	0.129-1	0.180-1
λ = 996.1	30000	0.101-1	0.630-2	0.114-1	0.154-1
$3kT/2\Delta E$ = 0.48	40000	0.876-2	0.546-2	0.106-1	0.139-1
	80000	0.702-2		0.936-2	0.114-1
SI III $4s^3S-4p^3P^o$	10000	0.728	0.438	0.604	0.932
mult. 2	20000	0.514	0.310	0.473	0.693
λ = 4560.1	30000	0.420	0.253	0.422	0.594
$3kT/2\Delta E$ = 0.48	40000	0.364	0.219	0.395	0.538
	80000	0.289		0.350	0.438
SI III $4s^1S-4p^1P^o$	10000	1.25	0.736	1.02	1.59
mult. 4	20000	0.887	0.520	0.811	1.19
λ = 5739.7	30000	0.724	0.468	0.729	1.02
$3kT/2\Delta E$ = 0.97	40000	0.640		0.686	0.927
	80000	0.518		0.613	0.760
SI III $4p^3P^o-4d^3D$	10000	0.762	0.456	0.746	1.06
mult. 5	20000	0.546	0.347	0.590	0.800
λ = 3801.4	30000	0.463		0.529	0.691
$3kT/2\Delta E$ = 1.3	40000	0.411		0.496	0.630
	80000	0.342		0.438	0.520
SI III $4p^3P^o-5s^3S$	10000	0.793	0.438	0.680	1.04
mult. 6	20000	0.571	0.326	0.555	0.792
λ = 3237.8	30000	0.500		0.507	0.688
$3kT/2\Delta E$ = 1.2	40000	0.458		0.481	0.628
	80000	0.409		0.433	0.521
SI IV $3s^2S-3p^2P^o$	10000	0.141-1	0.733-2	0.104-1	0.170-1
mult. 1UV	20000	0.995-2	0.518-2	0.764-2	0.122-1
λ = 1396.7	30000	0.812-2	0.423-2	0.651-2	0.102-1
$3kT/2\Delta E$ = 0.15	40000	0.703-2	0.366-2	0.588-2	0.902-2
	80000	0.497-2	0.259-2	0.484-2	0.691-2

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
SI IV $3p^2P^o$-$3d^2D$	10000	0.109-1	0.659-2	0.116-1	0.156-1
mult. 3UV	20000	0.768-2	0.466-2	0.856-2	0.114-1
λ = 1126.4	30000	0.627-2	0.380-2	0.730-2	0.955-2
$3kT/2\Delta E$ = 0.18	40000	0.543-2	0.329-2	0.659-2	0.851-2
	80000	0.384-2	0.233-2	0.541-2	0.670-2
SI IV $4s^2S$-$4p^2P^o$	10000	0.605	0.281	0.388	0.700
mult. 1	20000	0.428	0.199	0.298	0.512
λ = 4097.9	30000	0.349	0.162	0.263	0.432
$3kT/2\Delta E$ = 0.43	40000	0.302	0.140	0.245	0.386
	80000	0.230		0.216	0.305
SI IV $4p^2P^o$-$4d^2D$	10000	0.467	0.233	0.355	0.576
mult. 2	20000	0.346		0.281	0.429
λ = 3160.3	30000	0.297		0.253	0.367
$3kT/2\Delta E$ = 2.5	40000	0.267		0.237	0.332
	80000	0.213		0.211	0.270
SI IV $4d^2D$-$5p^2P^o$	10000	1.20	0.576	0.866	1.46
mult. 3	20000	0.884		0.692	1.09
λ = 3766.0	30000	0.763		0.625	0.930
$3kT/2\Delta E$ = 2.5	40000	0.701		0.589	0.841
	80000	0.593		0.529	0.683
SI IV $5p^2P^o$-$6s^2S$	10000	3.37	1.46	2.29	4.03
mult. 4	20000	2.55	1.27	1.89	3.03
λ = 4323.5	30000	2.24		1.74	2.61
$3kT/2\Delta E$ = 1.7	40000	2.12		1.66	2.37
	80000	1.84		1.51	1.93
SI IV $5d^2D$-$6f^2F^o$	10000	8.34		6.03	7.67
mult. 5	20000	7.09		5.39	6.34
λ = 4212.4	30000	6.39		5.04	5.71
$3kT/2\Delta E$ = 140.	40000	5.97		4.80	5.32
	80000	4.91		4.22	4.49

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
P III $4s^2S-4p^2P^o$	10000	0.531	0.326	0.446	0.682
mult. 3	20000	0.375	0.230	0.347	0.507
λ = 4230.4	30000	0.306	0.188	0.309	0.434
$3kT/2\Delta E$ = 0.44	40000	0.265	0.163	0.289	0.392
	80000	0.206		0.255	0.319
P III $4s^4P^o-4p^4P$	10000	0.462		0.388	0.594
mult. 9	20000	0.327		0.301	0.441
λ = 3943.5	30000	0.267		0.268	0.377
$3kT/2\Delta E$ = 8.9	40000	0.231		0.250	0.341
	80000	0.176		0.220	0.277
P III $4p^2P^o-4d^2D$	10000	0.477	0.297	0.491	0.683
mult. 4	20000	0.349		0.390	0.516
λ = 3228.8	30000	0.296		0.350	0.447
$3kT/2\Delta E$ = 1.7	40000	0.269		0.328	0.408
	80000	0.219		0.290	0.339
P IV $4s^3S-4p^3P^o$	10000	0.330	0.158	0.216	0.385
mult. 1	20000	0.233	0.112	0.165	0.281
λ = 3355.9	30000	0.191	0.912-1	0.144	0.237
$3kT/2\Delta E$ = 0.35	40000	0.165	0.790-1	0.134	0.211
	80000	0.121	0.648-1	0.117	0.166
P IV $4s^1S-4p^1P^o$	10000	0.565	0.264	0.363	0.653
mult. 2	20000	0.399	0.186	0.279	0.477
λ = 4249.6	30000	0.326	0.152	0.246	0.403
$3kT/2\Delta E$ = 0.44	40000	0.282	0.132	0.229	0.360
	80000	0.215		0.202	0.285
S III $3d^3P_o-4p^3P$	10000	0.216	0.135	0.221	0.301
mult. 2	20000	0.153	0.954-1	0.168	0.223
λ = 3346.2	30000	0.125	0.779-1	0.147	0.190
$3kT/2\Delta E$ = 0.41	40000	0.108	0.675-1	0.135	0.171
	80000	0.773-1		0.116	0.139

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
S III $3d^3P^o-4p^3S$	10000	0.205	0.128	0.209	0.286
mult. 3	20000	0.145	0.904-1	0.159	0.212
λ = 3233.4	30000	0.119	0.738-1	0.139	0.181
3kT/2ΔE = 0.40	40000	0.103	0.640-1	0.128	0.163
	80000	0.736-1		0.110	0.132
S III $3d^3D^o-4p^3P$	10000	0.302	0.193	0.309	0.421
mult. 8	20000	0.214	0.137	0.235	0.312
λ = 3950.5	30000	0.175	0.112	0.206	0.266
3kT/2ΔE = 0.46	40000	0.151	0.966-1	0.189	0.240
	80000	0.108		0.162	0.195
S III $3s^3P^o-4p^3D$	10000	0.472	0.277	0.388	0.598
mult. 4	20000	0.334	0.196	0.303	0.444
λ = 4287.1	30000	0.273	0.160	0.270	0.380
3kT/2ΔE = 0.46	40000	0.236	0.139	0.252	0.343
	80000	0.183		0.223	0.280
S III $4s^3P^o-4p^3P$	10000	0.389	0.229	0.322	0.495
mult. 5	20000	0.275	0.162	0.251	0.368
λ = 3840.0	30000	0.225	0.132	0.223	0.314
3kT/2ΔE = 0.45	40000	0.194	0.115	0.208	0.284
	80000	0.148		0.184	0.231
S III $3s^3P^o-4p^3S$	10000	0.364	0.214	0.302	0.465
mult. 6	20000	0.258	0.152	0.235	0.345
λ = 3692.3	30000	0.210	0.124	0.209	0.295
3kT/2ΔE = 0.45	40000	0.182	0.107	0.195	0.266
	80000	0.138		0.173	0.217
S IV $3p^2P^o-4s^2S$	10000	0.396-2	0.202-2	0.306-2	0.503-2
	20000	0.280-2	0.143-2	0.231-2	0.366-2
λ = 553.1	30000	0.229-2	0.117-2	0.201-2	0.308-2
3kT/2ΔE = 0.32	40000	0.198-2	0.101-2	0.185-2	0.275-2
	80000	0.144-2	0.784-3	0.159-2	0.217-2

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
S IV $4s^2S-4p^2P^o$	10000	0.245	0.118	0.162	0.287
mult. 1	20000	0.173	0.838-1	0.123	0.209
λ = 3104.1	30000	0.141	0.684-1	0.107	0.176
$3kT/2\Delta E$ = 0.35	40000	0.122	0.592-1	0.991-1	0.156
	80000	0.886-1	0.476-1	0.861-1	0.123
CL III $3d^4P-4p^4P^o$	10000	0.286	0.175	0.288	0.392
mult. 7	20000	0.202	0.123	0.218	0.290
λ= 4045.8	30000	0.165	0.101	0.190	0.246
$3kT/2\Delta E$ = 0.47	40000	0.143	0.873-1	0.174	0.222
	80000	0.102		0.149	0.179
CL III $4s^4P-4p^4D^o$	10000	0.284	0.171	0.238	0.363
mult. 1	20000	0.201	0.121	0.184	0.268
λ= 3629.0	30000	0.164	0.987-1	0.163	0.229
$3kT/2\Delta E$ = 0.47	40000	0.142	0.855-1	0.151	0.206
	80000	0.106		0.133	0.167
CL III $4s^4P-4p^4P^o$	10000	0.246	0.148	0.207	0.315
mult. 2	20000	0.174	0.104	0.160	0.233
λ = 3330.9	30000	0.142	0.853-1	0.141	0.199
$3kT/2\Delta E$ = 0.42	40000	0.123	0.739-1	0.132	0.179
	80000	0.908-1		0.116	0.145
CL III $4s^4P-4p^4S^o$	10000	0.226	0.135	0.190	0.290
mult. 3	20000	0.160	0.956-1	0.147	0.214
λ = 3160.1	30000	0.130	0.781-1	0.130	0.183
$3kT/2\Delta E$ = 0.40	40000	0.113	0.676-1	0.121	0.165
	80000	0.831-1		0.106	0.134
CL III $4s^2P-4p^2D^o$	10000	0.314	0.194	0.266	0.404
mult. 5	20000	0.222	0.137	0.206	0.299
λ = 3739.4	30000	0.181	0.112	0.182	0.255
$3kT/2\Delta E$ = 0.53	40000	0.157	0.982-1	0.170	0.231
	80000	0.118		0.149	0.187

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
CL III $4s^2P-4p^2P^o$	10000	0.243	0.157	0.212	0.318
mult. 6	20000	0.172	0.111	0.164	0.236
λ = 3300.9	30000	0.140	0.905-1	0.145	0.201
$3kT/2\Delta E$ = 0.45	40000	0.121	0.784-1	0.135	0.182
	80000	0.897-1		0.118	0.147
CL III $4s'\,^2D-4p'\,^2F^o$	10000	0.271	0.165	0.229	0.348
mult. 10	20000	0.192	0.117	0.177	0.257
λ = 3543.8	30000	0.157	0.953-1	0.156	0.219
$3kT/2\Delta E$ = 0.59	40000	0.136	0.859-1	0.145	0.198
	80000	0.100		0.128	0.160
CL III $4s'\,^2D-4p'\,^2D^o$	10000	0.252	0.153	0.213	0.324
mult. 11	20000	0.178	0.108	0.165	0.240
λ = 3394.2	30000	0.146	0.885-1	0.146	0.204
$3kT/2\Delta E$ = 0.55	40000	0.126	0.785-1	0.135	0.184
	80000	0.932-1		0.119	0.149
CL III $4s'\,^2D-4p'\,^2P^o$	10000	0.204	0.123	0.173	0.263
mult. 11UV	20000	0.144	0.871-1	0.134	0.195
λ = 2975.4	30000	0.118	0.711-1	0.118	0.166
$3kT/2\Delta E$ = 0.45	40000	0.102	0.616-1	0.110	0.150
	80000	0.748-1		0.963-1	0.121
CL IV $4s^3P^o-4p^3D$	10000	0.162	0.991-1	0.122	0.200
	20000	0.114	0.701-1	0.924-1	0.146
λ = 3082.2	30000	0.933-1	0.572-1	0.806-1	0.123
$3kT/2\Delta E$ = 0.32	40000	0.808-1	0.496-1	0.743-1	0.110
	80000	0.589-1	0.391-1	0.643-1	0.870-1
CL IV $4s^3P^o-4p^3P$	10000	0.131	0.819-1	0.100	0.164
	20000	0.924-1	0.579-1	0.760-1	0.119
λ = 2767.6	30000	0.755-1	0.473-1	0.662-1	0.101
$3kT/2\Delta E$ = 0.32	40000	0.653-1	0.409-1	0.609-1	0.899-1
	80000	0.472-1	0.314-1	0.526-1	0.710-1

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
A III 3d"$^3P^o$-4p"^3P	10000	0.164	0.114	0.183	0.238
mult. 6	20000	0.116	0.806-1	0.139	0.176
λ = 3432.6	30000	0.949-1	0.658-1	0.120	0.150
3kT/2ΔE = 0.42	40000	0.822-1	0.570-1	0.110	0.135
	80000	0.583-1		0.938-1	0.110
A III 4s$^5S^o$-4p^5P	10000	0.208	0.128	0.178	0.268
mult. 1	20000	0.147	0.906-1	0.137	0.198
λ = 3296.6	30000	0.120	0.740-1	0.120	0.169
3kT/2ΔE = 0.35	40000	0.104	0.641-1	0.112	0.152
	80000	0.763-1	0.522-1	0.978-1	0.123
A III 4s'$^3D^o$-4p'^3D	10000	0.238	0.144	0.200	0.304
mult. 2	20000	0.168	0.102	0.155	0.225
λ = 3492.1	30000	0.137	0.832-1	0.137	0.192
3kT/2ΔE = 0.37	40000	0.119	0.720-1	0.127	0.173
	80000	0.877-1	0.603-1	0.111	0.140
A III 4s'$^3D^o$-4p'^3F	10000	0.221	0.134	0.187	0.283
mult. 3	20000	0.156	0.946-1	0.144	0.209
λ = 3344.8	30000	0.128	0.772-1	0.127	0.178
3kT/2ΔE = 0.37	40000	0.110	0.669-1	0.118	0.161
	80000	0.813-1	0.553-1	0.104	0.130
A III 4s"$^3P^o$-4p"^3D	10000	0.141	0.807-1	0.117	0.178
mult. 4	20000	0.100	0.571-1	0.898-1	0.131
λ = 3041.4	30000	0.816-1	0.466-1	0.791-1	0.112
3kT/2ΔE = 0.40	40000	0.707-1	0.404-1	0.733-1	0.100
	80000	0.513-1		0.641-1	0.810-1
A IV 4s^4P-4p$^4D^o$	10000	0.117	0.716-1	0.888-1	0.145
mult. 4UV	20000	0.829-1	0.506-1	0.670-1	0.106
λ = 2810.9	30000	0.677-1	0.413-1	0.583-1	0.891-1
3kT/2ΔE = 0.29	40000	0.586-1	0.358-1	0.536-1	0.795-1
	80000	0.422-1	0.271-1	0.461-1	0.626-1

Element/Transition		T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
A IV	$4s\,^4P-4p\,^4P^o$	10000	0.102	0.631-1	0.781-1	0.127
	mult. 5UV	20000	0.721-1	0.446-1	0.589-1	0.926-1
	λ = 2617.5	30000	0.588-1	0.364-1	0.512-1	0.780-1
	$3kT/2\Delta E$ = 0.29	40000	0.510-1	0.315-1	0.470-1	0.696-1
		80000	0.365-1	0.234-1	0.404-1	0.548-1
A IV	$4s\,^2P-4p\,^2D^o$	10000	0.133	0.813-1	0.101	0.165
	mult. 2	20000	0.943-1	0.575-1	0.761-1	0.120
	λ = 2925.4	30000	0.770-1	0.469-1	0.663-1	0.101
	$3kT/2\Delta E$ = 0.31	40000	0.667-1	0.407-1	0.610-1	0.905-1
		80000	0.482-1	0.313-1	0.526-1	0.714-1
A IV	$4s'\,^2D-4p'\,^2F^o$	10000	0.114	0.701-1	0.868-1	0.142
	mult. 6UV	20000	0.806-1	0.496-1	0.654-1	0.103
	λ = 2769.2	30000	0.658-1	0.405-1	0.569-1	0.868-1
	$3kT/2\Delta E$ = 0.29	40000	0.570-1	0.350-1	0.523-1	0.775-1
		80000	0.410-1	0.263-1	0.449-1	0.610-1

4. Discussion and conclusions

From the results shown in Table 2, it appears that, for the specified temperature and electron density regions, agreement of modified semiempirical and semiclassical results with experiments is quite good. The errors seem to be random and are caused by uncertainties in both, calculations and experiments. The average values of the ratios of measured to calculated widths of ionized atoms are as follows: for doubly-ionized atoms, R_{SEM} = 1.06$\pm$0.32, R_{SE} = 1.53$\pm$0.46, R_{GM} = 0.96$\pm$0.24, R_G = 0.72$\pm$0.19; for triply-ionized atoms, R_{SEM} = 0.91$\pm$0.42, R_{SE} = 1.56$\pm$0.85, R_{GM} = 1.08$\pm$0.41, R_G = 0.72$\pm$0.32. The indicated error represents an average quadratic error calculated from $\sigma = \sqrt{\sum_{i=1}^{m} \Delta_i^2/m(m-1)}$ where Δ_i is the difference between the i-th average ratio for the multiplet and the average ratio for all multiplets.

The principal deficiency in the comparisons of theoretical results for doubly and triply ionized atoms with experiments comes from the lack of experimental line widths at higher electron temperatures.

At the present time there are not enough experimental data to show which modified approach is the better one, especially at high temperatures. If one draws a conclusion based on a single experiment for CIII and CIV lines [12], the modified semiclassical approach seems to describe the experiment better. However, it should be emphasized here that there is little difference between the results derived from the modified and unmodified semiclassical expressions at high electron temperatures.

From the examples in Fig. 1 it seems that the modified semiempirical formula agrees better with the experiments for singly ionized atom lines, than its unmodified version. This one may expect, since in most investigated examples the semiempirical formula can be used in "lumped together" form [1]. In these cases one can always count on higher accuracy of our modified version. However, for intermediate electron energies it is always better to take into account all perturbing levels separately.

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