

Article

Stark Broadening of O I Spectral Lines

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Abstract

We do not know a priori chemical composition of a star. However, with more high resolution spectra becoming more abundant thanks to the development of space-born observations, atomic data including Stark broadening parameters for various spectral lines for elements in various ionisation stages are becoming more feasible. Particularly are important spectral lines of C-N-O peak in the distribution of abundances of chemical elements. For the calculation of Stark broadening parameters, spectral line full widths at half intensity maximum (FWHM) and shifts, we used semiclassical perturbation method. As the result, Stark widths and shifts for 36 spectral lines of neutral oxygen, broadened by the collisions with electrons, protons and helium ions, have been obtained and compared with other theoretical calculations. These data are of interest for a number of problems in astrophysics, plasma physics, as well as for inertial fusion and various plasmas in technology.

Keywords: Stark broadening; O I; spectral lines; line profiles

1. Introduction

With the development of space born telescopes and astronomical instrumentation, the need for atomic data, including Stark broadening parameters, for spectra of elements in different ionization stages, is permanently increasing, since a great number of high resolution spectra is produced. The analysis of profiles of spectral lines, broadened by fluctuating electric microfields of surrounding charged particles (Stark broadening), gives possibility to determine many useful quantities for investigation of cosmic plasma. For example Stark broadening parameters - line widths and shifts, are useful for investigations of Cepheids and stellar pairs producing supernovae of the first type (SN I), as well as for determination of abundances of oxygen and its variation during the chemical evolution of the Universe. Such data are also of interest for radiative transfer calculations, stellar spectra interpretation, synthesis and modelling. They may find applications in other topics such as fusion [1], laser produced plasma research [2], and in general, plasma science [3] and technology [4–6].

Oxygen belongs to the C-N-O peak in the distribution of abundances of chemical elements, so that data for its spectral lines are particularly important. For example neutral oxygen spectral lines are used in a study of chemical abundance variations in the globular cluster M4 (NGC 6121) [7], for oxygen abundance analysis in A-type stars γ Gem (HD 41705), o Peg (HD 214994), θ Vir (HD 114330), and ν Cap (HD 193432) [8], in 17 spectroscopic binary stars in 15 young open clusters [9], for seven very and extremely metal-poor stars in the Large Magellanic Cloud [10], for 311 metal poor stars [11], Cepheid variables [12], for



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investigation of oxygen rich supernova remnants [13], supernovas [14,15], SN2023ufx and its progenitor [16], and O I (7773 Å) line is observed in the spectrum of V1405 Cas [17].

Due to the importance of data on oxygen lines, a lot of experimental results have been published, as for example by Jung [18], Wiese and Murphy [19], Morris and Garrison [20], Miller and Bengtson [21], Assous [22], Goly et al. [23], Goly and Weniger [24], Sohns and Kock [25], Mijatović et al. [26], Gerhard et al. [27] and Burger and Hermann [28]. Numerous calculations, using different theoretical methods, exist as well. Stark line widths and shifts for O I have been calculated using different variants of semiclassical theory [29–31] by Griem [29], Ben Nessib et al. [32], Riviere [33] and by Alonizan et al. [34]. The Model Microfield (MMM) Method [35] has been used by Brissaud et al. [36], the computer simulation modeling [37], has been applied by Stambulchik et al. [38] for Stark broadening of O I 777 nm triplet, while in Johns et al. [39] a modified semiempirical method based on the works of Dimitrijevic and Konjevic [40,41] has been employed.

Recently, we calculated, using the semiclassical perturbation method [30,31,42], Stark widths and shifts of neutral oxygen spectral lines, for plasma conditions corresponding to experimental data in Jung [18], Wiese and Murphy [19], Morris and Garrison [20], Miller and Bengtson [21], Assous [22], Goly et al. [23], Goly and Weniger [24], Sohns and Kock [25], Mijatović et al. [26], Gerhard et al. [27], Burger and Hermann [28] and compared experiment and theory concluding that the accordance is within the error bars. Here, our objective is to calculate Stark broadening data for temperatures ranging from 2500 K to 80,000 K, for 36 O I spectral lines, in order to cover the needs for stellar spectra analysis and synthesis, oxygen abundance determination, stellar atmosphere modeling and other uses, as e.g., for laboratory, laser produced and technological plasma, where such data are useful for example for plasma diagnostics, modelling, calculation of the corresponding absorption coefficient etc. We also compared our results with other theoretical calculations, when possible.

2. Theory

For the calculation of Stark full widths at half intensity maximum (FWHM) and shifts of spectral lines of neutral oxygen, the semiclassical perturbation theory [30,31,42] has been employed. It means that the radiating neutral atom is treated quantum mechanically, while perturbing particles, electrons and ions, are treated as classical particles. The connexion between these two systems is obtained using a time dependent potential. Besides the detailed description in above mentioned references, this theoretical approach has been presented many times, so that only basic expressions needed to understand how calculations have been performed, will be shown. The Stark FWHM (W) and shift (d) of an isolated, spectral line of a nonhydrogenic neutral atom, is:

$$W = N \int v f(v) dv \left(\sum_{i' \neq i} \sigma_{ii'}(v) + \sum_{f' \neq f} \sigma_{ff'}(v) + \sigma_{el} \right)$$

$$d = N \int v f(v) dv \int_{R_3}^{R_D} 2\pi \rho d\rho \sin(2\varphi_p), \quad (1)$$

where i and f are for the initial and final level of the corresponding transition; with i' and f' are denoted perturbing levels; N is perturber density; v perturber velocity, and $f(v)$ the Maxwellian distribution of electron velocities. The inelastic cross sections $\sigma_{kk'}(v)$, $k = i, f$ are calculated as an integral of the transition probability $P_{kk'}(\rho, v)$, over the impact parameter ρ :

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

The cross section for elastic collisions is given as:

$$\sigma_{el} = 2\pi R_2^2 + \int_{R_2}^{R_D} 2\pi\rho d\rho \sin^2 \delta,$$

$$\delta = (\varphi_p^2 + \varphi_q^2)^{\frac{1}{2}}. \quad (3)$$

Here, δ is the phase shift while φ_p (r^{-4}) and φ_q (r^{-3}), where r is the distance between the emitter and the perturber, are contributions due to polarization and quadrupole potentials. The calculation of cut-off parameters R_1 , R_2 , R_3 , and the Debye cut-off R_D is presented in detail in Sahal-Br  chot [31].

We can see from Equation (1), that the line width W is an integral over the summ of cross sections for processes depopulating the initial and final levels of the transition forming the considered spectral line. Namely such processes decrease the lifetime of the optical electron and, it is easy to show that according to the Heisenberg's uncertainty principle, atomic energy levels and the corresponding spectral line become broader.

The Stark widths (W) and shifts (d) can be used to obtain the line profile $F(\omega)$ (where ω is the angular frequency), using the expression:

$$F(\omega) = \frac{W/(2\pi)}{(\omega - \omega_{if} - d)^2 + (W/2)^2}. \quad (4)$$

Here

$$\omega_{if} = \frac{E_i - E_f}{\hbar},$$

where E_i and E_f are the energies of the initial and final atomic energy levels, respectively.

3. Results and Discussion

Employing the semiclassical perturbation theory [30,31,42], Stark broadening parameters of 36 spectral lines of neutral oxygen, W and d , have been calculated for broadening caused by the collisions with electrons, protons and helium ions (He II), which are usually the main constituents of stellar atmospheres. Atomic energy levels of neutral oxygen, which are needed for the determination of Stark widths and shifts, have been taken from Moore [43], and the oscillator strengths have been calculated within the Coulomb approximation [44,45].

The obtained results are presented in Tables 1 and 2. In Table 1 are FWHM and shifts for 36 O I transitions for broadening by the collisions with electrons and protons. Results are given for a perturber density of 10^{16} cm^{-3} and temperatures ranging from 2500 K to 80,000 K. In Table 2, analogous results are given for spectral lines broadened by the collisions with ionized helium (He II). In [46] the results for Stark widths of helium lines, obtained by the semiclassical perturbation theory [30,31] have been compared with critically selected experimental data for spectral lines within 13 He I multiplets and it has been found that the disagreement is within the limits of 20 percent. Since O I is more complicated we assume that the error bars in the present case are within the limits of 30 percent. In the case of the shift, due to mutual cancellations of different contributions, which decreases the accuracy, one can adopt the error bars as 30 percent of the corresponding width.

Table 1. Stark broadening parameters, W and d , for spectral lines of neutral oxygen (O I), broadened by the collisions with electrons and protons, are presented. Wavelengths, calculated from the used atomic energy levels, and parameter C [47] are also given. Dividing C with the FWHM, one obtains the maximal perturber density for which the line may be considered isolated. Results are presented for a perturber density of 10^{16} cm^{-3} and temperatures ranging from 2500 K to 80,000 K. A positive shift is towards the red part of the spectrum. An asterisk before a value indicates that this value is on the limit of validity of impact approximation.

Transition	T [K]	Electrons Width [Å]	Shift [Å]	Protons Width [Å]	Shift [Å]
Triplets					
O I 3S-3P 8448.8 Å $C = 0.54 \times 10^{19}$	2500	0.686×10^{-2}	0.321×10^{-2}	0.357×10^{-2}	0.854×10^{-3}
	5000	0.721×10^{-2}	0.376×10^{-2}	0.358×10^{-2}	0.965×10^{-3}
	10,000	0.822×10^{-2}	0.351×10^{-2}	0.361×10^{-2}	0.109×10^{-2}
	20,000	0.107×10^{-1}	0.306×10^{-2}	0.364×10^{-2}	0.122×10^{-2}
	40,000	0.145×10^{-1}	0.224×10^{-2}	0.368×10^{-2}	0.138×10^{-2}
	80,000	0.187×10^{-1}	0.180×10^{-2}	0.373×10^{-2}	0.155×10^{-2}
O I 3S-4P 4369.5 Å $C = 0.42 \times 10^{18}$	2500	0.926×10^{-2}	0.355×10^{-2}	0.465×10^{-2}	0.967×10^{-3}
	5000	0.107×10^{-1}	0.425×10^{-2}	0.468×10^{-2}	0.110×10^{-2}
	10,000	0.130×10^{-1}	0.478×10^{-2}	0.470×10^{-2}	0.125×10^{-2}
	20,000	0.161×10^{-1}	0.479×10^{-2}	0.473×10^{-2}	0.141×10^{-2}
	40,000	0.200×10^{-1}	0.372×10^{-2}	0.478×10^{-2}	0.159×10^{-2}
	80,000	0.236×10^{-1}	0.298×10^{-2}	0.485×10^{-2}	0.178×10^{-2}
O I 3S-5P 3693.6 Å $C = 0.13 \times 10^{18}$	2500	0.202×10^{-1}	-0.684×10^{-2}	0.999×10^{-2}	-0.211×10^{-2}
	5000	0.238×10^{-1}	-0.581×10^{-2}	0.101×10^{-1}	-0.244×10^{-2}
	10,000	0.297×10^{-1}	-0.392×10^{-2}	0.101×10^{-1}	-0.278×10^{-2}
	20,000	0.378×10^{-1}	-0.285×10^{-2}	0.102×10^{-1}	-0.315×10^{-2}
	40,000	0.459×10^{-1}	-0.200×10^{-2}	0.103×10^{-1}	-0.356×10^{-2}
	80,000	0.523×10^{-1}	-0.110×10^{-2}	0.104×10^{-1}	-0.401×10^{-2}
O I 3S-6P 3693.6 Å $C = 0.13 \times 10^{18}$	2500	0.202×10^{-1}	-0.685×10^{-2}	0.999×10^{-2}	-0.210×10^{-2}
	5000	0.238×10^{-1}	-0.573×10^{-2}	0.101×10^{-1}	-0.243×10^{-2}
	10,000	0.297×10^{-1}	-0.382×10^{-2}	0.101×10^{-1}	-0.277×10^{-2}
	20,000	0.378×10^{-1}	-0.272×10^{-2}	0.102×10^{-1}	-0.314×10^{-2}
	40,000	0.459×10^{-1}	-0.187×10^{-2}	0.103×10^{-1}	-0.355×10^{-2}
	80,000	0.523×10^{-1}	-0.100×10^{-2}	0.104×10^{-1}	-0.399×10^{-2}
O I 4S-4P 28,935.2 Å $C = 0.18 \times 10^{20}$	2500	0.452	-0.167	0.204	-0.434×10^{-1}
	5000	0.538	-0.196	0.205	-0.495×10^{-1}
	10,000	0.693	-0.196	0.206	-0.561×10^{-1}
	20,000	0.922	-0.177	0.208	-0.632×10^{-1}
	40,000	1.19	-0.138	0.210	-0.712×10^{-1}
	80,000	1.44	-0.112	0.213	-0.801×10^{-1}
O I 4S-5P 13,082.2 Å $C = 0.16 \times 10^{19}$	2500	0.280	-0.128	0.126	-0.324×10^{-1}
	5000	0.331	-0.135	0.128	-0.374×10^{-1}
	10,000	0.412	-0.126	0.129	-0.427×10^{-1}
	20,000	0.527	-0.111	0.131	-0.485×10^{-1}
	40,000	0.647	-0.928×10^{-1}	0.133	-0.549×10^{-1}
	80,000	0.741	-0.669×10^{-1}	0.135	-0.618×10^{-1}
O I 4S-6P 13,082.2 Å $C = 0.16 \times 10^{19}$	2500	0.280	-0.128	0.126	-0.323×10^{-1}
	5000	0.330	-0.134	0.128	-0.373×10^{-1}
	10,000	0.411	-0.125	0.129	-0.426×10^{-1}
	20,000	0.527	-0.110	0.130	-0.484×10^{-1}
	40,000	0.647	-0.915×10^{-1}	0.132	-0.548×10^{-1}
	80,000	0.741	-0.659×10^{-1}	0.135	-0.616×10^{-1}
O I 2P-3S 1303.5 Å $C = 0.20 \times 10^{18}$	2500	0.895×10^{-4}	0.809×10^{-4}	0.248×10^{-4}	0.230×10^{-4}
	5000	0.104×10^{-3}	0.931×10^{-4}	0.278×10^{-4}	0.261×10^{-4}
	10,000	0.124×10^{-3}	0.109×10^{-3}	0.312×10^{-4}	0.293×10^{-4}
	20,000	0.142×10^{-3}	0.124×10^{-3}	0.350×10^{-4}	0.330×10^{-4}
	40,000	0.153×10^{-3}	0.127×10^{-3}	0.393×10^{-4}	0.371×10^{-4}
	80,000	0.162×10^{-3}	0.116×10^{-3}	0.442×10^{-4}	0.417×10^{-4}

Table 1. Cont.

Transition	T [K]	Electrons Width [Å]	Shift [Å]	Protons Width [Å]	Shift [Å]
Triplets					
O I 2P-4S 1040.1 Å $C = 0.37 \times 10^{17}$	2500	0.436×10^{-3}	0.332×10^{-3}	0.101×10^{-3}	0.908×10^{-4}
	5000	0.513×10^{-3}	0.389×10^{-3}	0.113×10^{-3}	0.104×10^{-3}
	10,000	0.576×10^{-3}	0.451×10^{-3}	0.127×10^{-3}	0.118×10^{-3}
	20,000	0.608×10^{-3}	0.476×10^{-3}	0.143×10^{-3}	0.134×10^{-3}
	40,000	0.640×10^{-3}	0.444×10^{-3}	0.160×10^{-3}	0.150×10^{-3}
	80,000	0.689×10^{-3}	0.357×10^{-3}	0.180×10^{-3}	0.169×10^{-3}
O I 3P-4S 13,168.2 Å $C = 0.60 \times 10^{19}$	2500	0.714×10^{-1}	0.497×10^{-1}	0.168×10^{-1}	0.135×10^{-1}
	5000	0.821×10^{-1}	0.604×10^{-1}	0.184×10^{-1}	0.154×10^{-1}
	10,000	0.907×10^{-1}	0.674×10^{-1}	0.203×10^{-1}	0.175×10^{-1}
	20,000	0.102	0.683×10^{-1}	0.224×10^{-1}	0.198×10^{-1}
	40,000	0.116	0.549×10^{-1}	0.249×10^{-1}	0.223×10^{-1}
	80,000	0.138	0.436×10^{-1}	0.277×10^{-1}	0.251×10^{-1}
O I 2P-3D 1026.6 Å $C = 0.23 \times 10^{17}$	2500	0.322×10^{-3}	0.229×10^{-3}	0.114×10^{-3}	0.618×10^{-4}
	5000	0.371×10^{-3}	0.264×10^{-3}	0.119×10^{-3}	0.704×10^{-4}
	10,000	0.414×10^{-3}	0.293×10^{-3}	0.125×10^{-3}	0.799×10^{-4}
	20,000	0.453×10^{-3}	0.298×10^{-3}	0.132×10^{-3}	0.903×10^{-4}
	40,000	0.494×10^{-3}	0.271×10^{-3}	0.141×10^{-3}	0.102×10^{-3}
	80,000	0.542×10^{-3}	0.219×10^{-3}	0.151×10^{-3}	0.114×10^{-3}
O I 2P-4D 972.5 Å $C = 0.57 \times 10^{15}$	2500	0.588×10^{-2}	0.275×10^{-2}	$* 0.157 \times 10^{-2}$	$* 0.115 \times 10^{-2}$
	5000	0.575×10^{-2}	0.244×10^{-2}	$* 0.177 \times 10^{-2}$	$* 0.141 \times 10^{-2}$
	10,000	0.538×10^{-2}	0.202×10^{-2}	$* 0.202 \times 10^{-2}$	$* 0.167 \times 10^{-2}$
	20,000	0.497×10^{-2}	0.148×10^{-2}	$* 0.235 \times 10^{-2}$	$* 0.193 \times 10^{-2}$
	40,000	0.459×10^{-2}	0.928×10^{-3}	0.281×10^{-2}	0.222×10^{-2}
	80,000	0.421×10^{-2}	0.690×10^{-3}	0.345×10^{-2}	0.256×10^{-2}
O I 3P-3D 11,289.9 Å $C = 0.28 \times 10^{19}$	2500	0.371×10^{-1}	0.221×10^{-1}	0.151×10^{-1}	0.581×10^{-2}
	5000	0.411×10^{-1}	0.242×10^{-1}	0.154×10^{-1}	0.661×10^{-2}
	10,000	0.473×10^{-1}	0.232×10^{-1}	0.157×10^{-1}	0.749×10^{-2}
	20,000	0.573×10^{-1}	0.168×10^{-1}	0.162×10^{-1}	0.844×10^{-2}
	40,000	0.725×10^{-1}	0.115×10^{-1}	0.167×10^{-1}	0.951×10^{-2}
	80,000	0.869×10^{-1}	0.818×10^{-2}	0.174×10^{-1}	0.107×10^{-1}
O I 3P-4D 7004.1 Å $C = 0.29 \times 10^{17}$	2500	0.306	0.143	$* 0.812 \times 10^{-1}$	$* 0.596 \times 10^{-1}$
	5000	0.299	0.128	$* 0.918 \times 10^{-1}$	$* 0.731 \times 10^{-1}$
	10,000	0.280	0.102	$* 0.105$	$* 0.865 \times 10^{-1}$
	20,000	0.260	0.744×10^{-1}	$* 0.122$	$* 0.100$
	40,000	0.243	0.493×10^{-1}	0.146	0.115
	80,000	0.225	0.312×10^{-1}	0.179	0.133
O I 4P-4D 30,985.0 Å $C = 0.58 \times 10^{18}$	2500	6.09	2.78	$* 1.60$	$* 1.16$
	5000	6.00	2.38	$* 1.81$	$* 1.43$
	10,000	5.76	1.87	$* 2.06$	$* 1.69$
	20,000	5.56	1.24	$* 2.39$	$* 1.95$
	40,000	5.41	0.796	2.86	2.24
	80,000	5.21	0.490	3.51	2.59
O I 3D-4P 45,608.5 Å $C = 0.46 \times 10^{20}$	2500	1.07	0.354×10^{-2}	0.567	-0.256×10^{-1}
	5000	1.28	0.305×10^{-1}	0.568	-0.289×10^{-1}
	10,000	1.64	0.518×10^{-1}	0.569	-0.326×10^{-1}
	20,000	2.15	0.439×10^{-1}	0.569	-0.366×10^{-1}
	40,000	2.74	0.421×10^{-1}	0.570	-0.412×10^{-1}
	80,000	3.27	0.293×10^{-1}	0.572	-0.463×10^{-1}
O I 3D-5P 15,672.6 Å $C = 0.24 \times 10^{19}$	2500	0.394	-0.163	0.185	-0.428×10^{-1}
	5000	0.466	-0.165	0.187	-0.494×10^{-1}
	10,000	0.580	-0.133	0.189	-0.564×10^{-1}
	20,000	0.738	-0.118	0.190	-0.640×10^{-1}
	40,000	0.899	-0.869×10^{-1}	0.193	-0.723×10^{-1}
	80,000	1.02	-0.630×10^{-1}	0.196	-0.814×10^{-1}
O I 3D-6P 15,672.6 Å $C = 0.24 \times 10^{19}$	2500	0.394	-0.166	0.185	-0.426×10^{-1}
	5000	0.466	-0.163	0.187	-0.492×10^{-1}
	10,000	0.580	-0.132	0.189	-0.562×10^{-1}
	20,000	0.738	-0.116	0.190	-0.638×10^{-1}
	40,000	0.899	-0.860×10^{-1}	0.193	-0.721×10^{-1}
	80,000	1.02	-0.613×10^{-1}	0.196	-0.812×10^{-1}

Table 1. Cont.

Transition	T [K]	Electrons Width [Å]	Shift [Å]	Protons Width [Å]	Shift [Å]
Triplets					
O I 4D-5P 104,101.6 Å C = 0.65×10^{19}	2500	79.4	−35.3	19.8	* −13.4
	5000	81.0	−30.7	22.1	* −16.5
	10,000	81.6	−24.3	24.9	* −19.6
	20,000	83.3	−16.9	28.6	* −22.7
	40,000	85.7	−11.7	33.8	−26.0
	80,000	86.2	−8.12	41.1	−30.0
O I 4D-6P 104,101.6 Å C = 0.65×10^{19}	2500	79.3	−34.7	* 19.8	* −13.4
	5000	81.0	−30.8	* 22.1	* −16.5
	10,000	81.6	−24.6	* 24.9	* −19.5
	20,000	83.3	−16.9	* 28.5	* −22.7
	40,000	85.7	−11.6	33.8	−26.0
	80,000	86.2	−8.11	41.1	−30.0
Quintets					
O I 3S-3P 7775.5 Å C = 0.53×10^{19}	2500	0.448×10^{-2}	0.153×10^{-2}	0.245×10^{-2}	0.414×10^{-3}
	5000	0.463×10^{-2}	0.169×10^{-2}	0.245×10^{-2}	0.466×10^{-3}
	10,000	0.528×10^{-2}	0.167×10^{-2}	0.246×10^{-2}	0.525×10^{-3}
	20,000	0.694×10^{-2}	0.123×10^{-2}	0.247×10^{-2}	0.590×10^{-3}
	40,000	0.959×10^{-2}	0.917×10^{-3}	0.248×10^{-2}	0.663×10^{-3}
	80,000	0.125×10^{-1}	0.716×10^{-3}	0.249×10^{-2}	0.745×10^{-3}
O I 3S-4P 3948.5 Å C = 0.26×10^{18}	2500	0.704×10^{-2}	-0.795×10^{-3}	0.336×10^{-2}	-0.423×10^{-3}
	5000	0.815×10^{-2}	-0.188×10^{-4}	0.336×10^{-2}	-0.480×10^{-3}
	10,000	0.100×10^{-1}	0.682×10^{-3}	0.337×10^{-2}	-0.543×10^{-3}
	20,000	0.124×10^{-1}	0.119×10^{-2}	0.338×10^{-2}	-0.611×10^{-3}
	40,000	0.151×10^{-1}	0.989×10^{-3}	0.340×10^{-2}	-0.687×10^{-3}
	80,000	0.177×10^{-1}	0.786×10^{-3}	0.343×10^{-2}	-0.773×10^{-3}
O I 3S-5P 3349.2 Å C = 0.85×10^{17}	2500	0.193×10^{-1}	-0.829×10^{-2}	0.775×10^{-2}	-0.248×10^{-2}
	5000	0.223×10^{-1}	-0.697×10^{-2}	0.787×10^{-2}	-0.287×10^{-2}
	10,000	0.272×10^{-1}	-0.416×10^{-2}	0.801×10^{-2}	-0.329×10^{-2}
	20,000	0.339×10^{-1}	-0.250×10^{-2}	0.820×10^{-2}	-0.373×10^{-2}
	40,000	0.401×10^{-1}	-0.143×10^{-2}	0.845×10^{-2}	-0.423×10^{-2}
	80,000	0.451×10^{-1}	-0.409×10^{-3}	0.881×10^{-2}	-0.476×10^{-2}
O I 3S-6P 3123.0 Å C = 0.39×10^{17}	2500	0.496×10^{-1}	-0.274×10^{-1}	* 0.169×10^{-1}	* -0.695×10^{-2}
	5000	0.569×10^{-1}	-0.245×10^{-1}	* 0.175×10^{-1}	* -0.831×10^{-2}
	10,000	0.680×10^{-1}	-0.170×10^{-1}	* 0.182×10^{-1}	* -0.969×10^{-2}
	20,000	0.836×10^{-1}	-0.122×10^{-1}	0.190×10^{-1}	-0.111×10^{-1}
	40,000	0.965×10^{-1}	-0.742×10^{-2}	0.199×10^{-1}	-0.127×10^{-1}
	80,000	0.106	-0.277×10^{-2}	0.211×10^{-1}	-0.144×10^{-1}
O I 4S-4P 27,644.6 Å C = 0.13×10^{20}	2500	0.500	−0.254	0.172	-0.654×10^{-1}
	5000	0.572	−0.283	0.176	-0.748×10^{-1}
	10,000	0.680	−0.292	0.180	-0.849×10^{-1}
	20,000	0.840	−0.273	0.185	-0.962×10^{-1}
	40,000	1.04	−0.216	0.192	−0.108
	80,000	1.22	−0.176	0.201	−0.122
O I 4S-5P 12,270.6 Å C = 0.11×10^{19}	2500	0.279	−0.144	0.105	* -0.371×10^{-1}
	5000	0.321	−0.147	0.107	* -0.431×10^{-1}
	10,000	0.389	−0.118	0.110	-0.494×10^{-1}
	20,000	0.491	−0.103	0.113	-0.562×10^{-1}
	40,000	0.592	-0.789×10^{-1}	0.117	-0.637×10^{-1}
	80,000	0.671	-0.510×10^{-1}	0.123	-0.717×10^{-1}
O I 4S-6P 9697.5 Å C = 0.38×10^{18}	2500	0.489	−0.265	* 0.163	* -0.682×10^{-1}
	5000	0.561	−0.258	* 0.170	* -0.816×10^{-1}
	10,000	0.669	−0.189	* 0.177	* -0.951×10^{-1}
	20,000	0.828	−0.150	0.184	−0.109
	40,000	0.963	-0.963×10^{-1}	0.194	−0.125
	80,000	1.06	-0.427×10^{-1}	0.205	−0.141
O I 3P-4S 11,302.5 Å C = 0.46×10^{19}	2500	0.490×10^{-1}	0.349×10^{-1}	0.115×10^{-1}	0.950×10^{-2}
	5000	0.569×10^{-1}	0.417×10^{-1}	0.126×10^{-1}	0.108×10^{-1}
	10,000	0.634×10^{-1}	0.485×10^{-1}	0.140×10^{-1}	0.123×10^{-1}
	20,000	0.694×10^{-1}	0.492×10^{-1}	0.155×10^{-1}	0.139×10^{-1}
	40,000	0.766×10^{-1}	0.414×10^{-1}	0.173×10^{-1}	0.157×10^{-1}
	80,000	0.900×10^{-1}	0.317×10^{-1}	0.193×10^{-1}	0.177×10^{-1}

Table 1. Cont.

Transition	T [K]	Electrons Width [Å]	Shift [Å]	Protons Width [Å]	Shift [Å]
Quintets					
O I 3P-3D 9266.4 Å $C = 0.14 \times 10^{19}$	2500	0.314×10^{-1}	0.212×10^{-1}	0.105×10^{-1}	0.559×10^{-2}
	5000	0.358×10^{-1}	0.246×10^{-1}	0.109×10^{-1}	0.638×10^{-2}
	10,000	0.396×10^{-1}	0.248×10^{-1}	0.114×10^{-1}	0.724×10^{-2}
	20,000	0.442×10^{-1}	0.233×10^{-1}	0.121×10^{-1}	0.819×10^{-2}
	40,000	0.499×10^{-1}	0.182×10^{-1}	0.129×10^{-1}	0.921×10^{-2}
	80,000	0.563×10^{-1}	0.145×10^{-1}	0.140×10^{-1}	0.104×10^{-1}
O I 3P-4D 6159.0 Å $C = 0.39 \times 10^{17}$	2500	0.193	0.111	$* 0.469 \times 10^{-1}$	$* 0.352 \times 10^{-1}$
	5000	0.197	0.101	$* 0.526 \times 10^{-1}$	$* 0.425 \times 10^{-1}$
	10,000	0.192	0.868×10^{-1}	0.593×10^{-1}	0.499×10^{-1}
	20,000	0.184	0.668×10^{-1}	0.677×10^{-1}	0.576×10^{-1}
	40,000	0.175	0.457×10^{-1}	0.788×10^{-1}	0.657×10^{-1}
	80,000	0.165	0.301×10^{-1}	0.945×10^{-1}	0.748×10^{-1}
O I 4P-4D 26,514.7 Å $C = 0.72 \times 10^{18}$	2500	3.75	2.06	$* 0.885$	$* 0.653$
	5000	3.87	1.91	$* 0.990$	$* 0.791$
	10,000	3.84	1.64	1.11	0.928
	20,000	3.78	1.19	1.27	1.07
	40,000	3.74	0.815	1.47	1.22
	80,000	3.63	0.512	1.77	1.39
O I 3D-4P 59,761.5 Å $C = 0.60 \times 10^{20}$	2500	2.31	−1.13	0.903	−0.275
	5000	2.66	−1.09	0.913	−0.315
	10,000	3.16	−0.987	0.926	−0.357
	20,000	3.91	−0.751	0.943	−0.404
	40,000	4.74	−0.624	0.968	−0.455
	80,000	5.44	−0.464	1.01	−0.512
O I 3D-5P 11,950.4 Å $C = 0.58 \times 10^{18}$	2500	0.746	−0.398	$* 0.250$	$* -0.103$
	5000	0.860	−0.384	$* 0.260$	$* -0.123$
	10,000	1.03	−0.294	$* 0.270$	$* -0.144$
	20,000	1.26	−0.205	0.281	−0.165
	40,000	1.46	−0.131	0.296	−0.188
	80,000	1.60	-0.498×10^{-1}	0.313	−0.214
O I 3D-6P 16,114.7 Å $C = 0.20 \times 10^{19}$	2500	0.487	−0.231	0.186	-0.629×10^{-1}
	5000	0.568	−0.211	0.189	-0.730×10^{-1}
	10,000	0.686	−0.155	0.193	-0.836×10^{-1}
	20,000	0.856	−0.130	0.198	-0.951×10^{-1}
	40,000	1.02	−0.101	0.205	−0.108
	80,000	1.14	-0.600×10^{-1}	0.215	−0.121
O I 4D-5P 34,210.0 Å $C = 0.12 \times 10^{19}$	2500	11.4	−6.00	$* 2.63$	$* -1.46$
	5000	12.4	−5.72	$* 2.83$	$* -1.79$
	10,000	13.5	−4.43	$* 3.07$	$* -2.12$
	20,000	15.1	−3.13	$* 3.35$	$* -2.46$
	40,000	16.5	−2.06	3.73	−2.81
	80,000	17.2	−1.12	4.26	−3.20
O I 4D-6P 131,456.1 Å $C = 0.18 \times 10^{20}$	2500	111.	−56.9	$* 25.2$	$* -17.0$
	5000	118.	−53.2	$* 27.7$	$* -20.6$
	10,000	123.	−45.7	$* 30.8$	$* -24.2$
	20,000	129.	−32.2	34.6	−27.9
	40,000	135.	−23.2	39.7	−31.8
	80,000	137.	−14.6	47.0	−36.2

Table 2. Stark broadening parameters, W and d , for spectral lines of neutral oxygen (O I), broadened by the collisions with He II ions, are presented. Wavelengths, calculated from the used atomic energy levels, and parameter C [47] are also given. Dividing C with the FWHM, one obtains the maximal perturber density for which the line may be considered isolated. Results are presented for a perturber density of 10^{16} cm^{-3} and temperatures ranging from 2500 K to 80,000 K. A positive shift is towards the red part of the spectrum. An asterisk before a value indicates that this value is on the limit of validity of impact approximation. The empty places are because values for which the impact approximation is not valid are excluded.

Transition	T [K]	He II Width [Å]	Shift [Å]
Triplets			
O I 3S-3P 8448.8 Å $C = 0.54 \times 10^{19}$	2500	0.355×10^{-2}	0.701×10^{-3}
	5000	0.356×10^{-2}	0.794×10^{-3}
	10,000	0.357×10^{-2}	0.895×10^{-3}
	20,000	0.359×10^{-2}	0.101×10^{-2}
	40,000	0.362×10^{-2}	0.113×10^{-2}
	80,000	0.365×10^{-2}	0.127×10^{-2}
O I 3S-4P 4369.5 Å $C = 0.42 \times 10^{18}$	2500	0.463×10^{-2}	0.790×10^{-3}
	5000	0.465×10^{-2}	0.903×10^{-3}
	10,000	0.467×10^{-2}	0.103×10^{-2}
	20,000	0.469×10^{-2}	0.116×10^{-2}
	40,000	0.471×10^{-2}	0.131×10^{-2}
	80,000	0.474×10^{-2}	0.147×10^{-2}
O I 3S-5P 3693.6 Å $C = 0.13 \times 10^{18}$	2500	* 0.989×10^{-2}	* -0.172×10^{-2}
	5000	* 0.100×10^{-1}	* -0.199×10^{-2}
	10,000	0.101×10^{-1}	-0.228×10^{-2}
	20,000	0.101×10^{-1}	-0.259×10^{-2}
	40,000	0.102×10^{-1}	-0.293×10^{-2}
	80,000	0.102×10^{-1}	-0.330×10^{-2}
O I 3S-6P 3693.6 Å $C = 0.13 \times 10^{18}$	2500	* 0.989×10^{-2}	* -0.171×10^{-2}
	5000	* 0.100×10^{-1}	* -0.198×10^{-2}
	10,000	0.101×10^{-1}	-0.227×10^{-2}
	20,000	0.101×10^{-1}	-0.258×10^{-2}
	40,000	0.102×10^{-1}	-0.292×10^{-2}
	80,000	0.102×10^{-1}	-0.329×10^{-2}
O I 4S-4P 28,935.2 Å $C = 0.18 \times 10^{20}$	2500	0.203	-0.355×10^{-1}
	5000	0.204	-0.405×10^{-1}
	10,000	0.205	-0.460×10^{-1}
	20,000	0.206	-0.521×10^{-1}
	40,000	0.207	-0.586×10^{-1}
	80,000	0.208	-0.660×10^{-1}
O I 4S-5P 13,082.2 Å $C = 0.16 \times 10^{19}$	2500	* 0.125	* -0.262×10^{-1}
	5000	* 0.126	* -0.305×10^{-1}
	10,000	0.127	-0.350×10^{-1}
	20,000	0.128	-0.398×10^{-1}
	40,000	0.130	-0.451×10^{-1}
	80,000	0.131	-0.509×10^{-1}
O I 4S-6P 13,082.2 Å $C = 0.16 \times 10^{19}$	2500	* 0.125	* -0.261×10^{-1}
	5000	* 0.126	* -0.304×10^{-1}
	10,000	0.127	-0.349×10^{-1}
	20,000	0.128	-0.397×10^{-1}
	40,000	0.129	-0.450×10^{-1}
	80,000	0.131	-0.507×10^{-1}

Table 2. Cont.

Transition	T [K]	He II Width [Å]	Shift [Å]
Triplets			
O I 2P-3S 1303.5 Å $C = 0.20 \times 10^{18}$	2500	0.204×10^{-4}	0.189×10^{-4}
	5000	0.229×10^{-4}	0.214×10^{-4}
	10,000	0.257×10^{-4}	0.241×10^{-4}
	20,000	0.289×10^{-4}	0.272×10^{-4}
	40,000	0.324×10^{-4}	0.306×10^{-4}
	80,000	0.364×10^{-4}	0.344×10^{-4}
O I 2P-4S 1040.1 Å $C = 0.37 \times 10^{17}$	2500	0.831×10^{-4}	0.740×10^{-4}
	5000	0.932×10^{-4}	0.850×10^{-4}
	10,000	0.105×10^{-3}	0.968×10^{-4}
	20,000	0.118×10^{-3}	0.110×10^{-3}
	40,000	0.132×10^{-3}	0.124×10^{-3}
	80,000	0.148×10^{-3}	0.139×10^{-3}
O I 3P-4S 13,168.2 Å $C = 0.60 \times 10^{19}$	2500	0.145×10^{-1}	0.110×10^{-1}
	5000	0.158×10^{-1}	0.126×10^{-1}
	10,000	0.173×10^{-1}	0.143×10^{-1}
	20,000	0.190×10^{-1}	0.163×10^{-1}
	40,000	0.209×10^{-1}	0.183×10^{-1}
	80,000	0.232×10^{-1}	0.206×10^{-1}
O I 2P-3D 1026.6 Å $C = 0.23 \times 10^{17}$	2500	0.109×10^{-3}	0.504×10^{-4}
	5000	0.112×10^{-3}	0.577×10^{-4}
	10,000	0.116×10^{-3}	0.656×10^{-4}
	20,000	0.121×10^{-3}	0.743×10^{-4}
	40,000	0.127×10^{-3}	0.836×10^{-4}
	80,000	0.135×10^{-3}	0.941×10^{-4}
O I 2P-4D 972.5 Å $C = 0.57 \times 10^{15}$	2500	$* 0.129 \times 10^{-2}$	$* 0.896 \times 10^{-3}$
	5000	$* 0.144 \times 10^{-2}$	$* 0.113 \times 10^{-2}$
	10,000	$* 0.161 \times 10^{-2}$	$* 0.135 \times 10^{-2}$
	20,000	$* 0.181 \times 10^{-2}$	$* 0.158 \times 10^{-2}$
	40,000	$* 0.203 \times 10^{-2}$	$* 0.181 \times 10^{-2}$
	80,000	0.230×10^{-2}	0.206×10^{-2}
O I 3P-3D 11,289.9 Å $C = 0.28 \times 10^{19}$	2500	0.148×10^{-1}	0.475×10^{-2}
	5000	0.150×10^{-1}	0.542×10^{-2}
	10,000	0.152×10^{-1}	0.615×10^{-2}
	20,000	0.155×10^{-1}	0.695×10^{-2}
	40,000	0.158×10^{-1}	0.783×10^{-2}
	80,000	0.163×10^{-1}	0.881×10^{-2}
O I 3P-4D 7004.1 Å $C = 0.29 \times 10^{17}$	2500	$* 0.669 \times 10^{-1}$	$* 0.464 \times 10^{-1}$
	5000	$* 0.748 \times 10^{-1}$	$* 0.584 \times 10^{-1}$
	10,000	$* 0.836 \times 10^{-1}$	$* 0.700 \times 10^{-1}$
	20,000	$* 0.936 \times 10^{-1}$	$* 0.817 \times 10^{-1}$
	40,000	$* 0.105$	$* 0.939 \times 10^{-1}$
	80,000	0.119	0.107
O I 4P-4D 30,985.0 Å $C = 0.58 \times 10^{18}$	2500	$* 1.32$	$* 0.906$
	5000	$* 1.48$	$* 1.14$
	10,000	$* 1.65$	$* 1.36$
	20,000	$* 1.84$	$* 1.59$
	40,000	$* 2.07$	$* 1.83$
	80,000	2.34	2.08

Table 2. Cont.

Transition	T [K]	He II Width [Å]	Shift [Å]
Triplets			
O I 3D-4P 45,608.5 Å $C = 0.46 \times 10^{20}$	2500	0.566	-0.210×10^{-1}
	5000	0.568	-0.238×10^{-1}
	10,000	0.568	-0.268×10^{-1}
	20,000	0.569	-0.302×10^{-1}
	40,000	0.569	-0.339×10^{-1}
	80,000	0.569	-0.381×10^{-1}
O I 3D-5P 15,672.6 Å $C = 0.24 \times 10^{19}$	2500	* 0.183	* -0.347×10^{-1}
	5000	* 0.185	* -0.403×10^{-1}
	10,000	0.187	-0.462×10^{-1}
	20,000	0.188	-0.525×10^{-1}
	40,000	0.189	-0.595×10^{-1}
	80,000	0.191	-0.670×10^{-1}
O I 3D-6P 15,672.6 Å $C = 0.24 \times 10^{19}$	2500	* 0.183	* -0.346×10^{-1}
	5000	* 0.185	* -0.401×10^{-1}
	10,000	0.187	-0.460×10^{-1}
	20,000	0.188	-0.523×10^{-1}
	40,000	0.189	-0.593×10^{-1}
	80,000	0.191	-0.668×10^{-1}
O I 4D-5P 104,101.6 Å $C = 0.65 \times 10^{19}$	2500		
	5000	* 18.5	* −13.2
	10,000	* 20.3	* −15.8
	20,000	* 22.5	* −18.5
	40,000	* 24.9	* −21.2
	80,000	* 28.0	* −24.2
O I 4D-6P 104,101.6 Å $C = 0.65 \times 10^{19}$	2500		
	5000	* 18.5	* −13.2
	10,000	* 20.3	* −15.8
	20,000	* 22.5	* −18.5
	40,000	* 24.9	* −21.2
	80,000	* 28.0	* −24.2
Quintets			
O I 3S-3P 7775.5 Å $C = 0.53 \times 10^{19}$	2500	0.244×10^{-2}	0.340×10^{-3}
	5000	0.245×10^{-2}	0.384×10^{-3}
	10,000	0.245×10^{-2}	0.432×10^{-3}
	20,000	0.245×10^{-2}	0.486×10^{-3}
	40,000	0.246×10^{-2}	0.546×10^{-3}
	80,000	0.247×10^{-2}	0.614×10^{-3}
O I 3S-4P 3948.5 Å $C = 0.26 \times 10^{18}$	2500	0.335×10^{-2}	-0.347×10^{-3}
	5000	0.336×10^{-2}	-0.394×10^{-3}
	10,000	0.336×10^{-2}	-0.447×10^{-3}
	20,000	0.337×10^{-2}	-0.503×10^{-3}
	40,000	0.337×10^{-2}	-0.566×10^{-3}
	80,000	0.338×10^{-2}	-0.637×10^{-3}
O I 3S-5P 3349.2 Å $C = 0.85 \times 10^{17}$	2500	* 0.760×10^{-2}	* -0.200×10^{-2}
	5000	0.772×10^{-2}	-0.234×10^{-2}
	10,000	0.782×10^{-2}	-0.269×10^{-2}
	20,000	0.793×10^{-2}	-0.306×10^{-2}
	40,000	0.806×10^{-2}	-0.347×10^{-2}
	80,000	0.824×10^{-2}	-0.392×10^{-2}

Table 2. Cont.

Transition	T [K]	He II Width [Å]	Shift [Å]
Quintets			
O I 3S-6P 3123.0 Å $C = 0.39 \times 10^{17}$	2500		
	5000	$* 0.167 \times 10^{-1}$	$* -0.669 \times 10^{-2}$
	10,000	$* 0.172 \times 10^{-1}$	$* -0.788 \times 10^{-2}$
	20,000	$* 0.178 \times 10^{-1}$	$* -0.909 \times 10^{-2}$
	40,000	0.185×10^{-1}	-0.104×10^{-1}
	80,000	0.193×10^{-1}	-0.118×10^{-1}
O I 4S-4P 27,644.6 Å $C = 0.13 \times 10^{20}$	2500	0.169	-0.533×10^{-1}
	5000	0.171	-0.612×10^{-1}
	10,000	0.174	-0.697×10^{-1}
	20,000	0.177	-0.790×10^{-1}
	40,000	0.181	-0.891×10^{-1}
	80,000	0.187	-0.100
O I 4S-5P 12,270.6 Å $C = 0.11 \times 10^{19}$	2500	0.103	$* -0.300 \times 10^{-1}$
	5000	0.105	$* -0.351 \times 10^{-1}$
	10,000	0.106	-0.404×10^{-1}
	20,000	0.108	-0.461×10^{-1}
	40,000	0.111	-0.523×10^{-1}
	80,000	0.114	-0.591×10^{-1}
O I 4S-6P 9697.5 Å $C = 0.38 \times 10^{18}$	2500		
	5000	$* 0.162$	$* -0.657 \times 10^{-1}$
	10,000	$* 0.167$	$* -0.773 \times 10^{-1}$
	20,000	$* 0.173$	$* -0.893 \times 10^{-1}$
	40,000	0.179	-0.102
	80,000	0.187	-0.116
O I 3P-4S 11,302.5 Å $C = 0.46 \times 10^{19}$	2500	0.980×10^{-2}	0.775×10^{-2}
	5000	0.107×10^{-1}	0.888×10^{-2}
	10,000	0.118×10^{-1}	0.101×10^{-1}
	20,000	0.131×10^{-1}	0.115×10^{-1}
	40,000	0.145×10^{-1}	0.129×10^{-1}
	80,000	0.161×10^{-1}	0.145×10^{-1}
O I 3P-3D 9266.4 Å $C = 0.14 \times 10^{19}$	2500	0.998×10^{-2}	0.457×10^{-2}
	5000	0.103×10^{-1}	0.523×10^{-2}
	10,000	0.106×10^{-1}	0.594×10^{-2}
	20,000	0.111×10^{-1}	0.674×10^{-2}
	40,000	0.116×10^{-1}	0.758×10^{-2}
	80,000	0.123×10^{-1}	0.854×10^{-2}
O I 3P-4D 6159.0 Å $C = 0.39 \times 10^{17}$	2500	$* 0.391 \times 10^{-1}$	$* 0.277 \times 10^{-1}$
	5000	$* 0.435 \times 10^{-1}$	$* 0.341 \times 10^{-1}$
	10,000	$* 0.484 \times 10^{-1}$	$* 0.405 \times 10^{-1}$
	20,000	$* 0.540 \times 10^{-1}$	$* 0.470 \times 10^{-1}$
	40,000	0.603×10^{-1}	0.538×10^{-1}
	80,000	0.678×10^{-1}	0.612×10^{-1}
O I 4P-4D 26,514.7 Å $C = 0.72 \times 10^{18}$	2500	$* 0.742$	$* 0.514$
	5000	$* 0.823$	$* 0.634$
	10,000	$* 0.913$	$* 0.753$
	20,000	$* 1.02$	$* 0.873$
	40,000	1.13	1.00
	80,000	1.27	1.14

Table 2. *Cont.*

Transition	T [K]	He II Width [Å]	Shift [Å]
Quintets			
O I 3D-4P 59,761.5 Å $C = 0.60 \times 10^{20}$	2500	0.892	−0.224
	5000	0.900	−0.258
	10,000	0.908	−0.293
	20,000	0.917	−0.332
	40,000	0.930	−0.374
	80,000	0.947	−0.422
O I 3D-5P 11,950.4 Å $C = 0.58 \times 10^{18}$	2500		
	5000	* 0.248	
	10,000	* 0.255	* −0.117
	20,000	* 0.264	* −0.135
	40,000	0.274	−0.154
	80,000	0.286	−0.175
O I 3D-6P 16,114.7 Å $C = 0.20 \times 10^{19}$	2500	* 0.182	* -0.508×10^{-1}
	5000	* 0.185	* -0.594×10^{-1}
	10,000	0.188	-0.684×10^{-1}
	20,000	0.191	-0.780×10^{-1}
	40,000	0.195	-0.885×10^{-1}
	80,000	0.200	−0.100
O I 4D-5P 34,210.0 Å $C = 0.12 \times 10^{19}$	2500		
	5000		
	10,000	* 2.70	* −1.71
	20,000	* 2.89	* −2.00
	40,000	* 3.11	* −2.30
	80,000	* 3.37	* −2.62
O I 4D-6P 131,456.1 Å $C = 0.18 \times 10^{20}$	2500	* 21.8	* −13.3
	5000	* 23.8	* −16.5
	10,000	* 25.9	* −19.6
	20,000	* 28.4	* −22.8
	40,000	31.2	−26.1
	80,000	34.6	−29.7

Concerning the behavior of the electron-impact widths with temperature (see e.g., [48,49], one can see from Equation (1) that the width is a sum of cross sections for collisions which depopulate the initial and final levels of the transition from which the considered spectral line originates. The behavior of cross sections for electron – neutral atom collisions with temperature is the following: They start from zero and increase with temperature until a maximum depending on the Maxwellian distribution of electron velocities and then slowly decrease. The behavior of electron-impact line width with temperature depends on the temperature behavior of the sum of the corresponding cross sections. If the temperature is in the increasing part, the width increases with temperature, if it is in the decreasing part, the width decreases. If the temperature range includes the maximum, the width will first increase and after the maximum decrease.

In Table 3, our results for Stark widths are compared for temperatures ranging from 5000 K to 40,000 K and a density of 10^{17} cm^{-3} , with Stark widths for 11 multiplets calculated by Griem [29] and 4 by Alonizan et al. [34]. Namely, their calculations cover temperatures only up to 40,000 K, which is not enough for the modelling of stellar atmospheres and other purposes like laser produced and fusion plasma diagnostics and investigation. In

Table 4, the same comparison is presented for the shifts. For these three calculations, the semiclassical perturbation theory has been used. The main differences between the version used here [30,31,42] and the version of Griem, presented in his book on spectral line broadening by plasmas [29], are the calculation of elastic collisions, cut-offs in integration and symmetrization of perturber velocities before and after collision. Alonizan et al. [34] used in their study on Stark broadening of neutral oxygen spectral lines the version applied in our work, but their oscillator strengths have been taken from TOP database [50]. Moreover they calculated data for nine O I transitions for temperatures ranging from 5000 K to 40,000 K while here are presented data for 36 transitions for temperatures ranging from 2500 K to 80,000 K covering especially needs for investigations of stellar atmospheres. We note that for the comparison we did not use linear interpolation from our results for the density of 10^{16} cm^{-3} , but we made calculations for the density of 10^{17} cm^{-3} , used in Griem [29] and Alonizan et al. [34]. Namely the linear interpolation is less accurate due to the influence of Debye shielding. This influence can be taken into account using the correction given in Griem [29].

In order to better see the similarities and differences of three calculations, in Tables 5 and 6 are given the ratios of Stark widths (Table 5) and shifts (Table 6) of Griem [29] and Alonizan et al. [34] with Stark widths and shifts from this work, for the lowest temperature of 5000 K and the highest from Tables 3 and 4, of 40,000 K. We took into account only transitions where all three calculations exist. We can see that for the widths (Table 3), in the case of Griem [29], the agreement is very good for lower temperatures except for the 1303.5 Å line where it is on the limit of theoretical error bars. For higher temperatures, the agreement is not so good but within the theoretical error bars. These differences arise due to different method for calculating elastic collisions, different integration cut-offs and the symmetrization of perturber velocities before and after collision. In the case of Alonizan et al. [34], practically there is no difference between the lowest and highest temperature. The ratios are very close both for collisions with electron and protons, or in the case of 7775.5 Å transition, they are within the theoretical error bars. Here, the differences arise only due to different methods for the calculation of oscillator strengths. In this paper, the Coulomb approximation [44,45] has been used, while Alonizan et al. [34] use oscillator strengths from the TOP database [50], calculated employing close coupling non relativistic R-matrix method [51,52]. One can see that in spite of differences in oscillator strengths the final results are very close.

The ratios for the shift are given in Table 6. One can see that the Griem's values are slightly smaller than ours, but the differences are within the theoretical error bars. The unique case with an extreme disagreement is for the lowest temperature (5000 K) for 3948.5 Å transition. Namely, Griem's result is -0.00683 and ours is -0.000188 which is very small and in both cases much smaller than the corresponding width value. We draw attention that in the case of the width all cross sections entering in Equation (1) are positive, while in the case of the line shift, contributions to the phase shift ϕ_p in Equation (1) are positive for virtual transitions to the perturbing levels above the considered atomic energy level and negative for perturbing levels below it. If these contributions are comparable, the shift will be much smaller than the width and the resulting accuracy will be poor.

Table 3. In this table, electron-impact widths from this work (W_{TW}) are compared with the semi-classical results of Griem [29] (W_G) and of Alonizan et al. [34] (W_A). The electron density is 10^{17} cm^{-3} .

Transition	T [K]	W_{TW} [Å]	W_G [Å]	W_A [Å]
Triplets				
O I 3S-3P 8448.8 Å $C = 0.54 \times 10^{20}$	5000	0.721×10^{-1}	0.788×10^{-1}	
	10,000	0.822×10^{-1}	0.103	
	20,000	0.107	0.139	
	40,000	0.145	0.181	
O I 3S-4P 4369.5 Å $C = 0.42 \times 10^{19}$	5000	0.107	0.117	0.116
	10,000	0.130	0.160	0.141
	20,000	0.161	0.214	0.175
	40,000	0.200	0.262	0.217
O I 2P-3S 1303.5 Å $C = 0.20 \times 10^{19}$	5000	0.104×10^{-2}	0.144×10^{-2}	0.112×10^{-2}
	10,000	0.124×10^{-2}	0.164×10^{-2}	0.133×10^{-2}
	20,000	0.142×10^{-2}	0.185×10^{-2}	0.151×10^{-2}
	40,000	0.153×10^{-2}	0.216×10^{-2}	0.162×10^{-2}
O I 3P-4S 13,168.2 Å $C = 0.60 \times 10^{20}$	5000	0.821	0.918	
	10,000	0.907	1.094	
	20,000	1.02	1.32	
	40,000	1.16	1.59	
O I 2P-3D 1026.6 Å $C = 0.23 \times 10^{18}$	5000	0.371×10^{-2}	0.418×10^{-2}	
	10,000	0.414×10^{-2}	0.488×10^{-2}	
	20,000	0.453×10^{-2}	0.570×10^{-2}	
	40,000	0.494×10^{-2}	0.646×10^{-2}	
O I 3P-4D 7004.1 Å $C = 0.29 \times 10^{18}$	5000	2.85	3.50	
	10,000	2.70	3.30	
	20,000	2.53	3.08	
	40,000	2.38	2.84	
Quintets				
O I 3S-3P 7775.5 Å $C = 0.53 \times 10^{20}$	5000	0.463×10^{-1}	0.456×10^{-1}	0.552×10^{-1}
	10,000	0.528×10^{-1}	0.630×10^{-1}	0.630×10^{-1}
	20,000	0.694×10^{-1}	0.894×10^{-1}	0.825×10^{-1}
	40,000	0.959×10^{-1}	0.121	0.113
O I 3S-4P 3948.5 Å $C = 0.26 \times 10^{19}$	5000	0.815×10^{-1}	0.906×10^{-1}	0.901×10^{-1}
	10,000	0.100	0.125	0.110
	20,000	0.124	0.164	0.137
	40,000	0.151	0.197	0.167
O I 3P-4S 11,302.5 Å $C = 0.46 \times 10^{20}$	5000	0.569	0.644	
	10,000	0.634	0.752	
	20,000	0.694	0.894	
	40,000	0.766	1.04	
O I 3P-3D 9266.4 Å $C = 0.14 \times 10^{20}$	5000	0.358	0.384	
	10,000	0.396	0.444	
	20,000	0.442	0.516	
	40,000	0.499	0.588	
O I 3P-4D 6159.0 Å $C = 0.39 \times 10^{18}$	5000	1.95	2.34	
	10,000	1.90	2.32	
	20,000	1.83	2.22	
	40,000	1.75	2.08	

Table 4. In this table, electron-impact shifts from this work (d_{TW}) are compared with the semiclassical results of Griem [29] (d_G) and of Alonizan et al. [34] (d_A). The electron density is 10^{17} cm^{-3} .

Transition	T [K]	d_{TW} [Å]	d_G [Å]	d_A [Å]
Triplets				
O I 3S-3P	5000	0.374×10^{-1}	0.358×10^{-1}	
8448.8 Å	10,000	0.350×10^{-1}	0.373×10^{-1}	
$C = 0.54 \times 10^{20}$	20,000	0.306×10^{-1}	0.356×10^{-1}	
	40,000	0.224×10^{-1}	0.310×10^{-1}	
O I 3S-4P	5000	0.419×10^{-1}	0.331×10^{-1}	0.480×10^{-1}
4369.5 Å	10,000	0.475×10^{-1}	0.356×10^{-1}	0.527×10^{-1}
$C = 0.42 \times 10^{19}$	20,000	0.479×10^{-1}	0.358×10^{-1}	0.532×10^{-1}
	40,000	0.371×10^{-1}	0.330×10^{-1}	0.414×10^{-1}
O I 2P-3S	5000	0.927×10^{-3}	0.872×10^{-3}	0.975×10^{-3}
1303.5 Å	10,000	0.108×10^{-2}	0.100×10^{-2}	0.115×10^{-2}
$C = 0.20 \times 10^{19}$	20,000	0.124×10^{-2}	0.110×10^{-2}	0.130×10^{-2}
	40,000	0.127×10^{-2}	0.110×10^{-2}	0.134×10^{-2}
O I 3P-4S	5000	0.596	0.548	
13,168.2 Å	10,000	0.669	0.597	
$C = 0.60 \times 10^{20}$	20,000	0.683	0.594	
	40,000	0.548	0.532	
O I 2P-3D	5000	0.259×10^{-2}	0.256×10^{-2}	
1026.6 Å	10,000	0.291×10^{-2}	0.273×10^{-2}	
$C = 0.23 \times 10^{18}$	20,000	0.297×10^{-2}	0.270×10^{-2}	
	40,000	0.271×10^{-2}	0.248×10^{-2}	
O I 3P-4D	5000	1.03	1.20	
7004.1 Å	10,000	0.869	0.999	
$C = 0.29 \times 10^{18}$	20,000	0.693	0.805	
	40,000	0.482	0.628	
Quintets				
O I 3S-3P	5000	0.168×10^{-1}	0.144×10^{-1}	0.182×10^{-1}
7775.5 Å	10,000	0.167×10^{-1}	0.143×10^{-1}	0.181×10^{-1}
$C = 0.53 \times 10^{20}$	20,000	0.123×10^{-1}	0.130×10^{-1}	0.135×10^{-1}
	40,000	0.917×10^{-2}	0.108×10^{-1}	0.102×10^{-1}
O I 3S-4P	5000	-0.188×10^{-3}	-0.683×10^{-2}	-0.443×10^{-6}
3948.5 Å	10,000	0.688×10^{-2}	-0.172×10^{-2}	0.735×10^{-2}
$C = 0.26 \times 10^{19}$	20,000	0.119×10^{-1}	0.298×10^{-2}	0.127×10^{-1}
	40,000	0.989×10^{-2}	0.597×10^{-2}	0.108×10^{-1}
O I 3P-4S	5000	0.410	0.377	
11,302.5 Å	10,000	0.481	0.416	
$C = 0.46 \times 10^{20}$	20,000	0.491	0.419	
	40,000	0.414	0.379	
O I 3P-3D	5000	0.243	0.223	
9266.4 Å	10,000	0.246	0.228	
$C = 0.14 \times 10^{20}$	20,000	0.233	0.214	
	40,000	0.182	0.184	
O I 3P-4D	5000	0.891	0.945	
6159.0 Å	10,000	0.791	0.813	
$C = 0.39 \times 10^{18}$	20,000	0.646	0.668	
	40,000	0.452	0.527	

Table 5. In this table, ratios of Stark widths of Griem [29] (W_G) and of Alonizan et al. [34] (W_A) with Stark widths from this work (W_{TW}) are presented. The electron density is 10^{17} cm^{-3} .

Transition	T [K]	Electrons W_G/W_{TW}	W_A/W_{TW}	Protons W_A/W_{TW}
Triplets				
O I 3S-4P	5000	1.09	1.08	1.05
4369.5 Å	40,000	1.31	1.08	1.05
O I 2P-3S	5000	1.38	1.08	1.05
1303.5 Å	40,000	1.41	1.06	1.05
Quintets				
O I 3S-3P	5000	0.98	1.19	1.28
7775.5 Å	40,000	1.26	1.18	1.27
O I 3S-4P	5000	1.11	1.11	1.17
3948.5 Å	40,000	1.30	1.11	1.16

Table 6. In this table, ratios of Stark shifts of Griem [29] (d_G) and of Alonizan et al. [34] (d_A) with Stark shifts from this work (d_{TW}) are presented. The electron density is 10^{17} cm^{-3} .

Transition	T [K]	Electrons d_G/d_{TW}	d_A/d_{TW}	Protons d_A/d_{TW}
Triplets				
O I 3S-4P	5000	0.79	1.15	1.12
4369.5 Å	40,000	0.89	1.12	1.11
O I 2P-3S	5000	0.94	1.05	1.05
1303.5 Å	40,000	0.87	1.06	1.05
Quintets				
O I 3S-3P	5000	0.86	1.08	1.09
7775.5 Å	40,000	1.18	1.11	1.09
O I 3S-4P	5000	36	0.06	1.06
3948.5 Å	40,000	0.60	1.09	1.06

4. Conclusions

Electron-, proton-, and ionized helium-impact broadening parameters, FWHM, and shifts, for 36 O I transitions have been calculated with the help of the impact semiclassical perturbation theory [30,31,42]. We note that in previous calculations number of considered transitions is smaller, 23 in Griem [29], 4 in Ben Nessib et al. [32] and 9 in Alonizan et al. [34], while here, it is 36. Moreover, in the mentioned articles, the temperature range is from 5000 K to 40,000 K while here, it is from 2500 K to 80,000 K, so that the obtained data cover the needs of modern space-based spectroscopy. The results are compared with the theoretical calculations of Griem [29] and Alonizan et al. [34] and in general, a good agreement between the values obtained from the different calculations is observed.

The presented Stark broadening data are of interest for stellar spectra interpretation, analysis and synthesis, stellar abundance of oxygen determination and its variation during the evolution of the Universe, for modelling of stellar atmospheres, for laboratory plasma diagnostics and investigation and modelling of various plasmas in technology and fusion experiments.

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