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Article

Experimental and Theoretical Electron Collision Broadening Parameters for Several Yttrium Single Ionized (Y II) Spectral Lines of Astrophysical and Industrial Interest

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Abstract

Electron collision broadening parameters calculations were performed for 33 singly ionized yttrium spectral lines, 27 with special relevance in astrophysical applications (can be found in the Atmospheres of FGK Stars). Calculations were made in the semi-empirical Griem approach using the Gaunt factors proposed by Van Regemorter and those proposed by Douglas H. Sampson. Furthermore, to test our calculations, the electron collision broadening of 4 well isolated spectral lines of Y II was experimentally measured in laser-induced breakdown experiments using a Q-switched Nd:YAG laser focused on Pb-Y alloy samples.

Keywords: atomic data; atomic processes; Stark broadening

1. Introduction

Yttrium is a metallic chemical element that belongs to the group of rare earth elements. Currently, it plays an important role in a broad range of scientific (Astrophysics and atomic physics), technological, and industrial applications. Investigating the spectral lines of Yttrium, the atomic number 39 element, and its relative abundances compared to other elements is fundamental to deepening the knowledge, history, and classification of stars, because Yttrium is a neutron capture element and its study helps to understand the processes of nucleosynthesis in the early epochs of the galaxy (early universe) and its temporal evolution [1–3].

Furthermore, the Stark broadening of lines originating from energy levels with high principal quantum numbers of Y II may be important for the analysis of some lines in the atmospheres of cooler stars [4,5].

In optoelectronics, yttrium compounds are widely used as luminescent materials in display technologies and solid-state lighting devices. Yttrium is a key constituent of high-temperature superconductors, such as yttrium barium copper oxide, which is employed in the development of electrical power transmission systems, superconducting magnets, and high-sensitivity detection technologies. Yttrium oxide (Y₂O₃) is used in the production of advanced refractory ceramics exhibiting high thermal, chemical, and mechanical stability, allowing operation under extreme conditions in industrial furnaces. In medicine, yttrium is applied in oncological treatments, particularly in selective internal radiotherapy procedures.

Yttrium aluminum garnet (YAG) is a fundamental material in industrial laser applications. Neodymium-doped YAG lasers are among the most widely used solid-state laser systems.

For all these reasons, there are several experimental and theoretical works on Y II in the literature, mainly in the field of transition probabilities and lifetimes [5–8]. However, there is insufficient data

on the electron collision broadening parameters of its spectral lines. In their 1996 article, Popovic et al. discussed this need to provide electron collider broadening data for Y II spectral lines, but they only provided calculations for 6 multiplets [5]. Unfortunately, this is all that is available in the literature. Consequently, further experimental benchmarks are required to assess the reliability of existing semi-empirical approaches. The present work aims to address this gap by providing new experimental measurements and complementary theoretical calculations of Stark broadening parameters for a selected set of Y II spectral lines

The 33 lines analyzed in this work were chosen due to their presence in the atmospheres of FGK stars [3].

2. Materials and Methods

2.1. Experimental Setup

Different fluoride–lead–diluted yttrium glass samples were prepared in our laboratory. The mixtures were heated at 700 °C in a ceramic crucible in an air atmosphere for 12 h. The glass sample was not prepared with silica as a result of probable UV radiation absorption of silicate. The fundamental wavelength (1.06 μm) of a Q-switched Nd:YAG laser (Quanta-Ray PRO-350 de Spectra-Physics) was focused on these samples in several laser-induced breakdown (LIB) experiments to obtain several spectral lines of singly ionized yttrium (including the 3327.876 Å, 3361.98 Å, 3496.079 Å and 3549.005 Å spectral lines), neutral and single ionized lead, and the H α line. The energy per pulse (10 ns width) was measured at the target surface and was found to be 2.5 J. To avoid self-absorption of the yttrium spectral lines, the yttrium content in the samples was approximately 0.02%

A picture of the experimental setup is shown in Figure 1a and is analogous to the one used by these authors in a recent work [9].

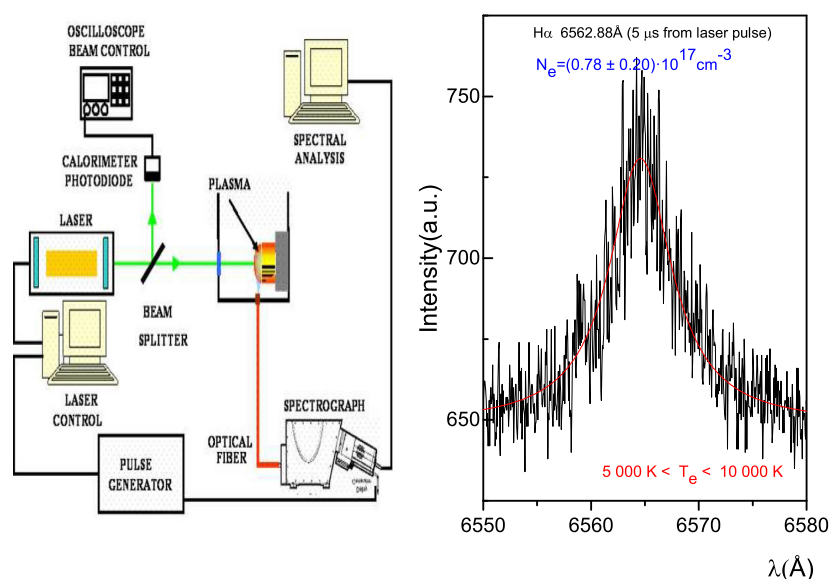


Figure 1. [a]Photographic view of the LIB (and LSP) irradiation experimental setup. [b]Fitting of a Voigt profile to the experimental H line emission from the plasma with a gate time of 500 ns at 5 μs delay time with a wavelength range from 6530 to 6590 Å.

A simple lens ($f = 20 \text{ cm}$, biconvex) focuses the laser light on the sample. There is also a vessel with water supply system via hose connection, which provides a confined environment in permanent circulation (used only in LSP experiments) and a programmable 3D positioning system; the sample is over it, which allows us to control the distances between the lens and the sample and thus the spot size. The emission spectra were acquired using a spectrograph (Horiba Jobin Yvon FHR1000) equipped with a CCD camera (Andor, model iStar 334T). The CCD of this camera is bidimensional, 1024×1024 pixels ($26 \times 26 \mu\text{m}^2$ size per pixel), which allowed us to study the plasma spatially. The camera was

time-controlled in both gate and delay with a maximum resolution of 100 ns. The spectrometer is equipped with a diffraction grating of 1800 groves/mm and covers a wavelength region of 200 to 700 nm. The emitted light was transferred to the spectrograph through a 0.5 mm diameter quartz fiber cable.

The data were taken by placing the optical fiber in the direction normal to the plasma emission and at a distance of 2 mm from the target surface (where the best signal-to-noise ratio was found). The spectra obtained were stored on a computer for further analysis.

Examples of the obtained spectra are shown in Figure 2. We have used the numerical facilities of the Microcal Origin program itself, where we analyze the spectral lines. This program fits a Voigt profile with four free parameters: the baseline position, the spectral line position, the Gaussian width, and the Lorentzian width. In the figure, the red line is the adjusted Voigt profile.

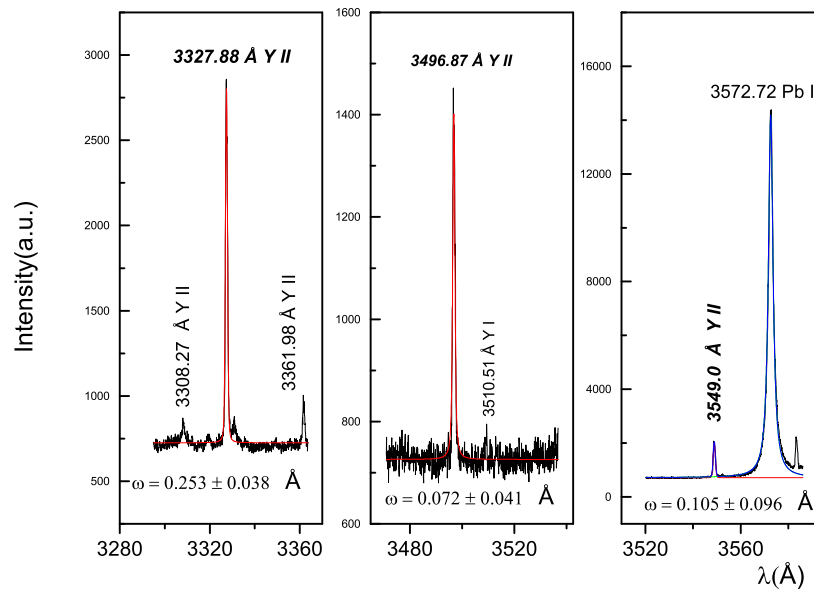


Figure 2. Three examples of Spectral emission of Y-Pb sample at 5 μ s after laser pulse in the 3280 at 3560 $\text{\AA}$ range. The figure shows, ω , the Lorentzian broadening of several Y II interest spectral lines (3327.88, 3496.87 and 3549.0 $\text{\AA}$) at the temperature and electron density of the plasmas generated in this experiment.

2.2. Electron Densities Measurement

The determination of the electron density was made by fitting a Voigt profile to the experimental $H\alpha$ line emission. In Figure 1b, we display a sample of the $H\alpha$ line (the red line is the adjusted Voigt profile).

This profile was analyzed two times: first using plasma diagnostic tables using the Lyman and Balmer hydrogen lines [10]. The second using the following expression (1) [11] was used to obtain the electron number density, N_e , from the width of the H alpha line. This is a semi-empirical equation perfectly described in the bibliography.

$$N_e = 8.02 \cdot 10^{12} \left(\frac{\Delta\lambda_{1/2}}{\alpha_{1/2}} \right)^{3/2} \text{ cm}^{-3} \quad (1)$$

where $\Delta\lambda_{1/2}$ is the FWHM (Full Width at Half Maximum) of the line in $\text{\AA}$, and $\alpha_{1/2}$ is half the width of the reduced Stark profiles in $\text{\AA}$, and their precise values can be found in Kepple and Griem [12]. A value between 5000 and 10 000 K was used (values compatible with the redshift of the line $H\alpha$) to choose the value $\alpha_{1/2}$ from the table included in the paper mentioned above.

The electron density obtained for both procedures in our experiments for a delay from the laser pulse of 5 μ s was compatible with a value of $(0.78 \pm 0.20) \cdot 10^{17} \text{ cm}^{-3}$. This result is identical, within

experimental limits, to that obtained in our previous work [13] since the experimental conditions are identical except for the small traces of yttrium added that replace the small traces of scandium

2.3. Temperature Measurement

As in our previous work on Ti II [14], plasma temperatures at the different time windows were determined from Boltzmann plots using several Pb I lines (see Figure 3) with upper level energies in the range 4.4–6.1 eV and well-known transition probabilities [15]. The resulting temperature before a self-absorption correction at 5.0 μ s was $(13\,800 \pm 1\,500)$ K.

To minimize the influence of self-absorption effects, corrections were applied following established procedures [16]. In this procedure, we used our experimental lorentzian FWHM for the spectral lines and the experimental Stark broadening parameters of [17]. The resulting temperature after a self-absorption correction at 5.0 μ s was $(8\,900 \pm 1\,500)$ K. As expected, the temperature obtained was identical within experimental limits to that of our previous work mentioned above [9,14]. In addition, this temperature was compatible with the shift of the H α line planned by Griem [11] and used for us in [18].

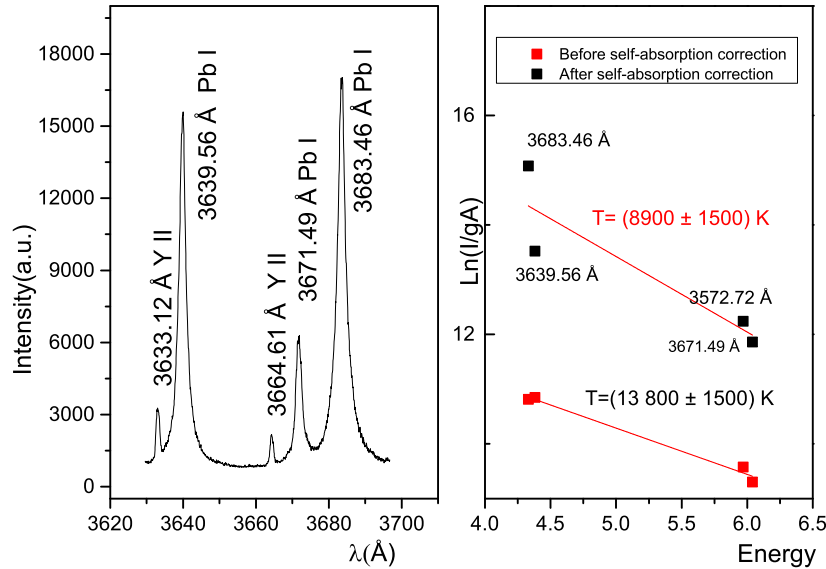


Figure 3. (a): Spectral emission of Y-Pb sample at 5 μ s after laser pulse in the 3630 at 3755 Å range. (b): Plasma temperature, at 5 μ s after the laser pulse, estimated by a Boltzmann plot from the lines displayed in Figure 3a.

3. Theoretical Calculations

In the same way as in our previous studies the Stark broadening parameters were calculated using the Equations (2) and (3) of semi-empirical Griem approximation [19] where Griem incorporated Baranger's work [20]. The Stark line width (HWHM), ω_{se} , and shift, d , in angular frequency units, were determined using these equations. Initially, the effective Gaunt factors by [21] and van Regemorter [22], denoted as g_{se} and g_{sh} , were used.

$$\omega_{se} \approx 8 \left(\frac{\pi}{3} \right)^{3/2} \frac{\hbar}{ma_0} N_e \left(\frac{E_H}{kT} \right)^{1/2} \left[\sum_{i'} |\langle i' | \vec{r} | i \rangle|^2 g_{se} \left(\frac{E}{\Delta E_{i'i}} \right) + \sum_{f'} |\langle f' | \vec{r} | f \rangle|^2 g_{se} \left(\frac{E}{\Delta E_{f'f}} \right) \right] \quad (2)$$

$$d \approx -8 \left(\frac{\pi}{3} \right)^{3/2} \frac{\hbar}{ma_0} N_e \left(\frac{E_H}{kT} \right)^{1/2} \times \left[\sum_{i'} \left(\frac{\Delta E_{i'i}}{|\Delta E_{i'i}|} \right) |\langle i' | \vec{r} | i \rangle|^2 g_{sh} \left(\frac{E}{\Delta E_{i'i}} \right) - \sum_{f'} \left(\frac{\Delta E_{f'f}}{|\Delta E_{f'f}|} \right) |\langle f' | \vec{r} | f \rangle|^2 g_{sh} \left(\frac{E}{\Delta E_{f'f}} \right) \right] \quad (3)$$

Additionally, E_H and $E=3/2$ kT represented the hydrogen ionization energy and the perturbing electron energy, respectively, with k as the Boltzmann constant. The free electron density and electron temperature were denoted as N_e and T . The transitions' initial and final levels were labeled as i and f with i' and f' representing the levels of Sc II with optical transitions corresponding to i and f . The energy differences between levels i' and i and levels f' and f were denoted $\Delta E_{i'i}$ and $\Delta E_{f'f}$, respectively. The expressions of the type $|\langle i' | \vec{r} | i \rangle|^2$ are the square of matrix elements of the optical transitions.

To facilitate the spectroscopic use of our results, conversion of the angular frequency obtained in Griem's expressions into units of wavelength was essential. This conversion was achieved using the equation $\Delta\lambda = \omega_{se}\lambda^2/\pi c$. In this equation, $\Delta\lambda$ represents the Stark broadening (full width at half maximum, FWHM), λ denotes the wavelength, and c represents the speed of light.

Cowan's code [23] was used to obtain the matrix elements required for Equations (2) and (3). In this way, we have used in our calculations 19 configurations of even parity namely, $5s^2$, $5s6s$, $5s7s$, $5s8s$, $6s^2$, $5s4d$, $5s5d$, $5s6d$, $5p^2$, $4d^2$, $4d6s$, $4d7s$, $4d8s$, $4d9s$, $4d5d$, $4d6d$, $4d7d$, $4d8d$, $4d5g$ and 11 configurations of odd parity namely, $5s5p$, $5s6p$, $5s4f$, $5s5f$, $4d5p$, $4d6p$, $4d7p$, $4d4f$, $4d5f$, $4d6f$ and $4d7f$.

To adjust our calculations, we used a previously cited work by A. E. Nilsson, S. Johansson, and R. L. Kurucz (Nilsson, 1991). This paper we used to obtain the experimental levels to which we could fit our theoretical levels. Following Cowan's recommendations, to get a good set of matrix elements, we have not forced the fits more than 1 % (As is well known a more precise fit is almost always achieved at the cost of worsening the fit of the transition probabilities (or, in other words, of the matrix elements).

Two sets of calculations were performed: using Regemorter's Gaunt factors and using for the calculation of Gaunt factors the expression (4) and the tables provided by [24].

$$g(x) = \frac{\sqrt{3}}{2\pi} \left\{ \ln x + H_i \left[\left(\frac{\Delta E_{ii'}}{I_i} \right)^{r_i} + A_i \left(\frac{\Delta E_{ii'}}{I_i} - 1 \right) \right] \left(1 - \frac{1}{x} \right) \right\} + \frac{\sqrt{3}}{2\pi} \left\{ 1.12i \left(\frac{\Delta E_{ii'}}{I_i} \right) \frac{1}{x} \right\} \quad (4)$$

where I_i is the ionization energy for level i and the values of H_i , r_i and A_i were tabulated by Sampson and Zhang.

Information about Y II spectral lines analyzed in our calculations can be seen in Table 1.

Table 1. Wavelengths and levels of the 33 lines included in our calculations.

	Wavelength λ (Å)	Transition			Wavelength λ (Å)	Transition		
		Upper	Lower			Upper	Lower	
1	3 242.272	4d5p $^3P_2^o$	4d5s 3D_3	18	4900.118	4d5p $^3D_2^o$	4d 2 3F_3	
2	3327.876	4d5p $^1F_3^o$	4d5s 1D_2	19	4982.128	4d5p $^3F_4^o$	4d 2 3F_3	
3	3361.98	5s5p $^1P_1^o$	4d 2 1D_2	20	5087.418	4d5p $^3F_4^o$	4d 2 3F_4	
4	3496.079	4d5p $^3D_1^o$	5s 2 1S_0	21	5119.11	4d5p $^3F_3^o$	4d 2 3F_2	
5	3549.005	4d5p $^3D_3^o$	4d5s 3D_2	22	5123.209	4d5p $^1P_1^o$	4d 2 3F_2	
6	3611.043	4d5p $^3D_2^o$	4d5s 3D_2	23	5200.409	4d5p $^3F_2^o$	4d 2 3F_2	
7	3788.693	4d5p $^3F_2^o$	4d5s 3D_1	24	5205.722	4d5p $^3F_3^o$	4d 2 3F_3	
8	3950.349	4d5p $^1D_2^o$	4d5s 3D_1	25	5289.815	4d5p $^3F_2^o$	4d 2 3F_3	
9	4124.904	4d5p $^3F_3^o$	4d5s 1D_2	26	5402.773	4d5p $^1F_3^o$	4d 2 1D_2	
10	4177.528	4d5p $^3F_2^o$	4d5s 1D_2	27	5473.384	4d5p $^3P_2^o$	4d 2 3P_1	
11	4235.727	5s5p $^1P_2^o$	4d5s 3D_2	28	5497.405	4d5p $^3P_2^o$	4d 2 3P_2	
12	4374.933	4d5p $^1D_2^o$	4d5s 1D_2	29	5544.61	4d5p $^3P_0^o$	4d 2 3P_1	
13	4398.008	5s5p $^3P_1^o$	4d5s 3D_2	30	5546.008	4d5p $^3P_1^o$	4d 2 3P_2	
14	4682.321	5s5p $^3P_2^o$	4d5s 1D_2	31	6613.731	4d5p $^3D_3^o$	4d 2 3P_2	
15	4823.304	4d5p $^3D_2^o$	4d 2 3F_2	32	6795.415	4d5p $^3D_2^o$	4d 2 3P_1	
16	4854.861	4d5p $^3D_1^o$	4d 2 3F_2	33	7881.878	4d5p $^1P_1^o$	4d 2 1D_2	
17	4883.682	4d5p $^3D_3^o$	4d 2 3F_4					

4. Discussion

The theoretical values of the Stark line widths and line shifts, ω (Å) and d (Å), normalized to an electron density of 10^{17} cm^{-3} (calculated using both Gaunt factors: van Regemorter and Sampson) are displayed in Table 2. The temperatures used in our calculations can be seen in the third column of the table. Calculations for temperatures other than those shown can be provided upon request.

Table 2. Stark widths and shifts, ω (Å) and d (Å), normalized to an electron density of 10^{17} cm^{-3} obtained in our calculations using the Gaunt factors provided by van Regemorter and Sampson. Our theoretical data are compared, when it is possible, with our experimental values and theoretical values of Popović [25].

	Wavelength λ (Å)	T (10 ³ K)	Regemorter		Sampson		This work	Ref [25]
			ω (Å)	d (Å)	ω (Å)	d (Å)	ω (Å)	ω (Å)
1	3 242.272	5.00	1.83	-0.60	0.37	-0.12		
		10.00	1.29	-0.43	0.27	-0.09		0.15
		20.00	0.91	-0.30	0.19	-0.06		
		50.00	0.58	-0.19	0.17	-0.04		
2	3327.876	5.00	1.97	-0.52	0.41	-0.11		
		8.90			0.30	-0.08	0.32±0.15	
		10.00	1.40	-0.37	0.29	-0.08		
		20.00	0.99	-0.26	0.20	-0.05		
3	3361.98	50.00	0.66	-0.15	0.43	-0.06		
		5.00	1.45	-0.56	0.30	-0.12		
		8.90			0.22	-0.09	0.50±0.20	
		10.00	1.03	-0.40	0.21	-0.08		
4	3496.079	20.00	0.73	-0.28	0.16	-0.06		
		50.00	0.50	-0.20	0.34	-0.16		
		5.00	0.76	-0.16	0.16	-0.03		
		8.90			0.12	-0.02	0.09±0.06	
5	3549.005	10.00	0.54	-0.12	0.11	-0.02		
		20.00	0.38	-0.08	0.08	-0.02		
		50.00	0.24	-0.05	0.08	0.00		
		5.00	2.14	-0.55	0.44	-0.11		
		8.90			0.33	-0.08	0.15±0.10	
6	3611.043							
		10.00	1.51	-0.39	0.31	-0.08		
		20.00	1.07	-0.27	0.22	-0.06		
		50.00	0.68	-0.17	0.22	-0.01		
7	3788.693	5.00	1.79	-0.51	0.37	-0.10		
		10.00	1.27	-0.36	0.26	-0.07		0.17
		20.00	0.90	-0.25	0.18	-0.05		
		50.00	0.57	-0.16	0.18	-0.01		
8	3950.349	5.00	1.39	-0.39	0.29	-0.08		
		10.00	0.99	-0.28	0.20	-0.06		
		20.00	0.70	-0.20	0.14	-0.04		
		50.00	0.44	-0.12	0.14	-0.01		
9	4124.904	5.00	1.56	-0.41	0.32	-0.08		
		10.00	1.10	-0.29	0.23	-0.06		
		20.00	0.78	-0.20	0.16	-0.04		
		50.00	0.49	-0.13	0.20	0.01		
10	4177.528	5.00	2.29	-0.67	0.47	-0.14		
		10.00	1.62	-0.48	0.33	-0.10		
		20.00	1.15	-0.34	0.24	-0.07		
		50.00	0.72	-0.21	0.28	-0.08		

Table 2. Cont.

	Wavelength λ (Å)	T (10 ³ K)	Regemorter		Sampson		This work	Ref [25]
			ω (Å)	d (Å)	ω (Å)	d (Å)	ω (Å)	ω (Å)
11	4235.727	5.00	1.94	-0.60	0.43	-0.14		
		10.00	1.37	-0.43	0.30	-0.10		0.21
		20.00	0.97	-0.30	0.21	-0.07		
		50.00	0.61	-0.19	0.20	-0.03		
12	4374.933	5.00	1.99	-0.91	0.41	-0.19		
		10.00	1.41	-0.65	0.29	-0.13		
		20.00	0.99	-0.46	0.22	-0.09		
		50.00	0.64	-0.28	0.18	-0.05		
13	4398.008	5.00	2.19	-0.63	0.45	-0.13		
		10.00	1.55	-0.45	0.32	-0.09		0.22
		20.00	1.09	-0.32	0.22	-0.07		
		50.00	0.68	-0.20	0.36	-0.04		
14	4682.321	5.00	1.75	-0.81	0.36	-0.17		
		10.00	1.23	-0.58	0.25	-0.12		
		20.00	0.87	-0.41	0.19	-0.08		
		50.00	0.56	-0.25	0.16	-0.05		
15	4823.304	5.00	2.25	-1.02	0.46	-0.21		
		10.00	1.59	-0.72	0.33	-0.15		
		20.00	1.12	-0.51	0.25	-0.10		
		50.00	0.72	-0.31	0.32	-0.11		
16	4854.861	5.00	2.51	-0.56	0.51	-0.12		
		10.00	1.77	-0.40	0.36	-0.08		
		20.00	1.25	-0.28	0.26	-0.06		
		50.00	0.82	-0.18	0.35	-0.03		
17	4883.682	5.00	1.78	-0.47	0.37	-0.10		
		10.00	1.26	-0.34	0.26	-0.07		
		20.00	0.89	-0.24	0.18	-0.05		
		50.00	0.59	-0.15	0.27	-0.05		
18	4900.118	5.00	3.86	-0.94	0.79	-0.19		
		10.00	2.73	-0.66	0.56	-0.14		
		20.00	1.93	-0.47	0.40	-0.10		
		50.00	1.26	-0.30	0.55	-0.08		
19	4982.128	5.00	2.85	-0.71	0.58	-0.15		
		10.00	2.01	-0.50	0.41	-0.10		
		20.00	1.42	-0.36	0.29	-0.07		
		50.00	0.93	-0.23	0.42	-0.06		
20	5087.418	5.00	3.70	-0.97	0.76	-0.20		
		10.00	2.62	-0.68	0.54	-0.14		
		20.00	1.85	-0.48	0.38	-0.10		
		50.00	1.20	-0.31	0.44	-0.10		
21	5119.11	5.00	4.14	-1.15	0.85	-0.24		
		10.00	2.93	-0.81	0.60	-0.17		
		20.00	2.07	-0.57	0.42	-0.12		
		50.00	1.34	-0.37	0.51	-0.13		
22	5123.209	5.00	2.98	-0.76	0.61	-0.16		
		10.00	2.11	-0.54	0.43	-0.11		
		20.00	1.49	-0.38	0.31	-0.08		
		50.00	0.97	-0.24	0.35	-0.07		
23	5200.409	5.00	1.91	-0.57	0.39	-0.12		
		10.00	1.35	-0.40	0.28	-0.08		
		20.00	0.95	-0.29	0.20	-0.06		
		50.00	0.66	-0.17	0.31	-0.05		

Table 2. Cont.

	Wavelength λ (Å)	T (10 ³ K)	Regemorter		Sampson		This work	Ref [25]
			ω (Å)	d (Å)	ω (Å)	d (Å)	ω (Å)	ω (Å)
24	5205.722	5.00	2.44	-0.65	0.50	-0.13		
		10.00	1.72	-0.46	0.35	-0.09		
		20.00	1.22	-0.33	0.25	-0.07		
		50.00	0.79	-0.21	0.33	-0.06		
25	5289.815	5.00	2.74	-0.80	0.69	-0.19		
		10.00	1.94	-0.57	0.49	-0.14		
		20.00	1.37	-0.40	0.35	-0.10		
		50.00	0.89	-0.26	0.42	-0.11		
26	5402.773	5.00	2.83	-0.83	0.58	-0.17		
		10.00	2.00	-0.58	0.41	-0.12		
		20.00	1.41	-0.41	0.29	-0.09		
		50.00	0.92	-0.27	0.41	-0.09		
27	5473.384	5.00	4.73	-1.13	0.97	-0.23		
		10.00	3.35	-0.80	0.69	-0.16		
		20.00	2.37	-0.56	0.49	-0.12		
		50.00	1.66	-0.35	1.06	-0.13		
28	5497.405	5.00	3.33	-0.79	0.68	-0.16		
		10.00	2.36	-0.56	0.48	-0.11		
		20.00	1.66	-0.39	0.35	-0.09		
		50.00	1.09	-0.25	0.44	-0.10		
29	5544.61	5.00	3.72	-0.98	0.76	-0.20		
		10.00	2.63	-0.69	0.54	-0.14		
		20.00	1.86	-0.48	0.41	-0.12		
		50.00	1.23	-0.32	0.53	-0.14		
30	5546.008	5.00	1.11	-0.38	0.23	-0.08		
		10.00	0.79	-0.27	0.16	-0.06		
		20.00	0.56	-0.19	0.13	-0.04		
		50.00	0.39	-0.13	0.18	-0.06		
31	6613.731	5.00	2.63	-0.77	0.54	-0.16		
		10.00	1.86	-0.55	0.38	-0.11		
		20.00	1.31	-0.38	0.30	-0.10		
		50.00	0.90	-0.27	0.38	-0.11		
32	6795.415	5.00	6.22	-1.29	1.28	-0.27		
		10.00	4.40	-0.91	0.90	-0.19		
		20.00	3.10	-0.64	0.68	-0.16		
		50.00	2.09	-0.43	0.86	-0.07		
33	7881.878	5.00	4.52	-0.89	0.93	-0.18		
		10.00	3.20	-0.63	0.66	-0.13		
		20.00	2.26	-0.45	0.48	-0.10		
		50.00	1.51	-0.29	0.62	-0.03		

Our experimental measurements of the Stark broadening of four of these spectral lines are shown in the penultimate column. In the last column, we present the scan Popović calculations [25] in the modified semi empirical approach. The raw comparison of both theoretical values has problems because, as can be seen in the cited reference, in Popović’s calculations only multiplets have been calculated. By a simple inspection it can be seen that our theoretical values agree well, within the margins suggested by Griem, with our experimental results.

As in our previous articles [13,14], the calculations with the Gaunt factors of Regemorter differ from the values calculated with Sampson’s Gaunt factors by a factor between 5 and 7. The calculations

performed with the expression proposed by Sampson and Zhang are very close to the experimental values, as can be seen in Figure 4.

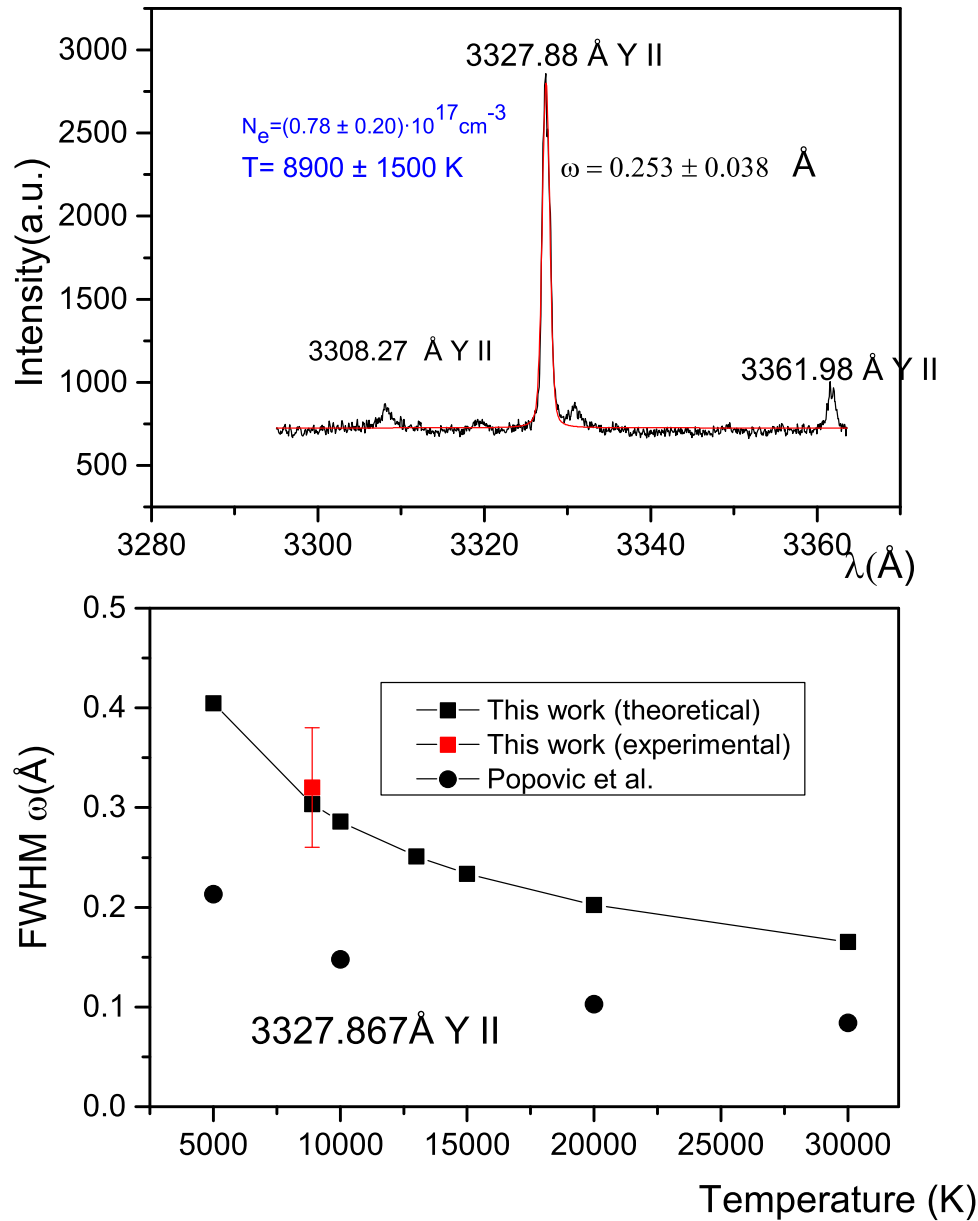


Figure 4. a) Spectral emission of Y-Pb sample at 5 μ s after laser pulse in the 3300 at 3360 Å range. b) Stark width (FWHM) normalized to $N_e = 10^{17} \text{ cm}^{-3}$ vs. temperature for 3327,867 Å spectral line of single ionized Yttrium.

As an example, in Figure 4 we present the calculated Stark width (FWHM), ω (Å), normalized to $N_e = 10^{17} \text{ cm}^{-3}$ vs temperature for the 3327.876 Å of single ionized Yttrium.

5. Conclusions

In this work, we performed Stark broadening measurements of 4 spectral lines of single-ionized yttrium and one spectral line of neutral scandium. These 4 experimental values are new in the bibliography. In addition, we have calculated the Stark broadening parameters, using the procedure suggested by Sampson to obtain the Gaunt factors, for 33 Y II spectral lines. In this way, we have obtained results close (around a factor of 1.5) to the experimental values of these 4 spectral lines. They have allowed us to assume that the calculations performed for 33 lines ranging between 3242.27 Å and 7881.88 Å are accurate using the Gaunt factors proposed by Sampson.

We are preparing a similar study of Th II. We are also preparing a study on the effect of traces of different elements (V, Ti, Sc, Y and Th) on the behavior of laser-generated plasmas on Pb samples.

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