



**HAL**  
open science

# CONTINUOUS EMISSION, LOWERING OF THE IONIZATION POTENTIAL AND TOTAL EXCITATION CROSS-SECTIONS OF AN ATMOSPHERIC THERMAL PLASMA

R. Rosado, D. Schram, J. Leclair

► **To cite this version:**

R. Rosado, D. Schram, J. Leclair. CONTINUOUS EMISSION, LOWERING OF THE IONIZATION POTENTIAL AND TOTAL EXCITATION CROSS-SECTIONS OF AN ATMOSPHERIC THERMAL PLASMA. *Journal de Physique Colloques*, 1979, 40 (C7), pp.C7-285-C7-286. 10.1051/jphyscol:19797140 . jpa-00219114

**HAL Id: jpa-00219114**

**<https://hal.science/jpa-00219114v1>**

Submitted on 4 Feb 2008

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

**CONTINUOUS EMISSION, LOWERING OF THE IONIZATION POTENTIAL AND TOTAL EXCITATION CROSS-SECTIONS OF AN ATMOSPHERIC THERMAL PLASMA**

R.J. Rosado, D.C. Schram and J. Leclair.

*Eindhoven University of Technology, Eindhoven, the Netherlands.*

Introduction. A careful study of the relation between the electron density,  $n_e$ , and the electron temperature,  $T_e$ , in an atmospheric arc plasma, shows an approach to local thermodynamic equilibrium (LTE) at large values of  $n_e$  [1]. Our measurements can be interpreted in terms of a Partial LTE (PLTE) model, in which the ground state is overpopulated with respect to the other excited states. This overpopulation is shown to be caused by radiative recombination in ref. [1].

The relative overpopulation of the ground state as a function of  $T_e$ , is fairly sensitive to small variations in, both, the transition probability,  $A$ , and the value for the lowering of the ionisation potential,  $\Delta\chi_0$ ; when an accurate value of  $A$  is available, an estimate of  $\Delta\chi_0$  can be made. The total cross-section for excitation from the neutral ground state was derived from the measured degree of overpopulation. In addition we calculated the emissivity of the free-bound UV recombination radiation, which proves to be quite large in the 70-80 nm spectral range. Finally, we give some results for the continuum radiation and for the Stark parameters at  $\lambda \approx 700$  nm.

Experimental method and data handling. The experimental method has been described in [1]. It is based on the assumption of PLTE. The source function,  $S$ , is then given by

$$S = \frac{\epsilon(\lambda)}{\kappa(\lambda)} = \frac{2hc^2}{\lambda^5} \left[ \exp\left(\frac{hc}{\lambda k T_e}\right) - 1 \right]^{-1}.$$

The source function has been determined for several transitions in the Ar neutral spectrum. To this end we measured emission and absorption ( $\lambda$ -)profiles of selected lines (with appropriate optical thickness;  $1 < \kappa(\lambda)l < 3$ ), at 300-1000  $\lambda$ -positions over the wavelength range of the line and its adjacent continuum. The line source function proved to be constant over the line profile, and close to the continuum source function.

The experimental profiles were then fitted with

theoretical voigt profiles, for  $\epsilon(\lambda)$  and  $\kappa(\lambda)$ , by a least squares minimisation procedure, with parameters: the source function, the optical thickness at the line center, the continuum absorption as a function of wavelength, the position of the line center, the lorentzian width of the line, and a factor accounting for the total transmissivity of the optical system. The gaussian component of the profiles was set equal to the Doppler width at  $T_e$ . Each theoretical profile was then convolved with the measured apparatus profile of the monochromator used, and compared with the measured profile. Iteratively the best fit was obtained. In this way  $T_e$  was determined using all the available information. In addition, line broadening parameters and continuum emissivities were obtained.  $n_e$  was calculated from the emission coefficient using Saha's equation. The neutral density,  $n_0$ , followed from Dalton's law ( $p = \Sigma nkT$ ). This value of  $n_0$  was then compared with the value,  $n_{0,s}$ , obtained from LTE, in order to calculate the overpopulation of  $n_0$ .

Results. The measurements, mainly on the 696.5 nm line, were carried out in an atmospheric, water cooled arc plasma. The channel diameter is  $5.10^{-3}$  m and the plasma length is  $9.7.10^{-2}$  m. The arc current was varied from 40 A to 250 A.

1. Influence of  $\Delta\chi_0$  and  $A$ . Figure 1 is a plot of the overpopulation of the ground level, expressed in  $b = n_0/n_{0,s} - 1$ , which shows the expected asymptotic behaviour, approaching 0 at large values of  $T_e$ . In the calculation of  $b(T_e)$  we used  $A = 67 \cdot 10^5$  and  $\Delta\chi_0$  from Ecker and Kroll's formula (cf. [2]). The function  $b(T_e)$  is very sensitive to variations  $\delta A$  in  $A$  and  $\delta(\Delta\chi_0)$  in  $\Delta\chi_0$ :

$$\delta b \approx \frac{n_e}{n_{0,s}} \frac{\delta(\Delta\chi_0)}{kT_e} + \frac{\delta A}{A}.$$

In particular at high temperatures, when  $n_e/n_{0,s}$  becomes large and the asymptotic behaviour of  $b(T_e)$  is known, minimization of  $\delta b$  can provide additional

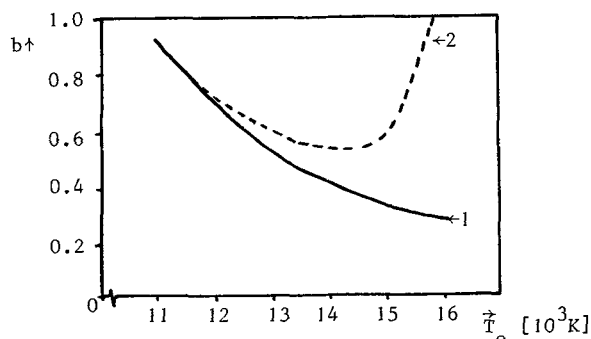


Fig. 1 Overpopulation factor  $b = n_0/n_{0,s} - 1$  as a function of  $T_e$ , for Ar at 1 atm.

curve (1) with  $\Delta\chi_0$  from Ecker-Kroll  
curve (2) with  $\Delta\chi_0$  from Unsold, Ecker-Weizel, Brunner

information on A and  $\Delta\chi_0$ . Assuming A to be more accurately known than  $\Delta\chi_0$  we investigated the effect of different assumptions in the calculation of  $\Delta\chi_0$  on  $b(T_e)$ . The result is given in fig. 1, in which curve 2 is the  $b(T_e)$  relation obtained with the same value of A as in curve 1, but a different value of  $\Delta\chi_0$ : a mean value from the calculations of Unsold, Ecker-Weizel and Brunner (e.g. [2]). As can be seen curve 2 does not show the expected asymptotic behaviour, indicating that Ecker and Kroll's formula, in which the Debye length is used instead of the interparticle distance, is more satisfactory.

**2. Total excitation cross-section.** Assuming that radiative recombination to the ground level is the dominant mechanism causing the overpopulation in our PLTE model, we find, using the principle of detailed balancing:

$$b = \frac{n_e}{n_{0,s}} \frac{\beta_{3p}^{(2)}(T_e)}{\gamma_{3p}(T_e)}$$

$\beta_{3p}^{(2)}(T_e)$ , the radiative recombination coefficient, can easily be found from detailed balancing, using the published values for the photo-ionisation cross-section (cf. [3]). It is more difficult to obtain accurate values for  $\gamma_{3p}(T_e) = \Sigma \langle \sigma v_e \rangle_{exc} + \langle \sigma v_e \rangle_{ion}$ , the total excitation and ionisation cross-section from the ground level. Especially in the temperature range of interest (1-1.5 eV) the excitation cross-sections  $\sigma(v_e)$  are not accurately known and depend much on the threshold behaviour, which in its turn is also not accurately known. With theoretical values for  $\beta_{3p}^{(2)}(T_e)$ , [3], we have determined  $\gamma_{3p}(T_e)$  from the measured values of  $b$  and  $n_e$ . The result is given in fig. 2 (points). The qualitative dependence of  $\gamma_{3p}$  on  $T_e$  is as expected, although our values indicate that the threshold behaviour of  $\gamma_{3p}(T_e)$  is

less steep than indicated in the literature.

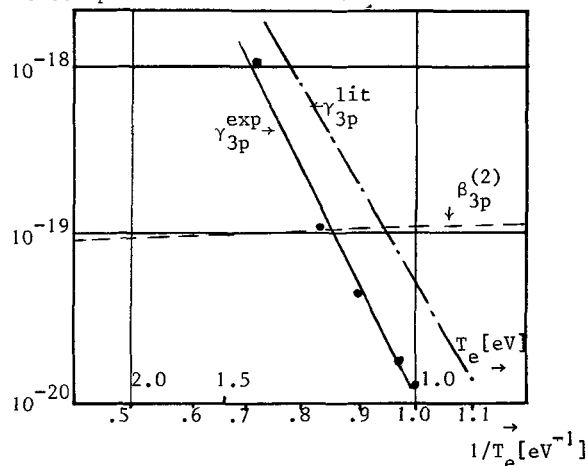


Fig. 2 Total excitation and ionisation cross-section  $\gamma_{3p}$  as function of  $T_e$ , for Ar at 1 atm. Also shown is the radiative recombination coef.  $\beta_{3p}^{(2)}$ .

$\gamma_{3p}^{lit}$ : literature values for  $\gamma_{3p}$ .  
 $\gamma_{3p}^{exp}$ : measured values for  $\gamma_{3p}$ .

**3. Continuum emission and Stark parameter.** Using the theoretical values for  $\beta_{3p}^{(2)}$ , we calculated the total power of the continuum free-bound radiation, which amounts to about 1 kW per cm arc length, for  $\lambda=72$  to 78 nm. This makes similar arcs very attractive as UV "light" sources. From our fitting procedure we also obtained the Biberman factor,  $\xi_{fb}$  (at  $\lambda=700$  nm) and the Stark broadening parameter,  $\alpha$ . The results are summarized in table 1. The continuum absorption and the  $\xi_{fb}$  values agree with Schlüter's values [4,5]. The mean value for  $\alpha$ ,  $\alpha \approx 7.4 \cdot 10^{-24} \text{ \AA m}^3$  differs by almost 40% from Griem's value,  $\alpha \approx 12 \cdot 10^{-24} \text{ \AA m}^3$  [6].

Table 1.

I	$T_e$ [A]	$n_e$ [ $10^{23} \text{ m}^{-3}$ ]	$K_{line}$ [ $\text{m}^{-1}$ ]	$K_{cont}$ [ $\text{m}^{-1}$ ]	$\xi_{ff}$	$\xi_{fb}$
60	12.4	0.7	35.1	0.10	1.23	1.73
100	13.4	1.2	37.1	0.36	1.24	1.84
140	14.3	1.6	34.0	0.56	1.24	1.89
180	15.0	1.8	29.9	0.66	1.24	1.99
220	15.4	1.9	27.8	0.70	1.24	2.05
250	16.0	2.0	21.7	0.71	1.24	2.05

References.

[1] Leclair, J. and Schram D.C. Proc. 13th ICPIG, Berlin (1977) p. 483.  
[2] Lochte-Holtgreven, ed., "Plasma Diagnostic" (1968) p. 157.  
[3] Katsonis, K., Thesis, Université de Paris-Sud (1962).  
[4] Schlüter, D., Z. Astrophys. 56, 43 (1962).  
[5] Schlüter, D., Z. Phys. 201 (1968), 80.  
[6] Griem, H., "Spectral line broadening by plasmas", academic Press (1974).