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EXPERIMENTAL VERIFICATION OF A COLLISIONAL RADIATIVE MODEL OF THE ARGON ION SPECTRUM

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Abstract: We determined experimentally population density inversions between upper and lower laser levels in the argon ion spectrum and compared the results with those of a Collisional Radiative model. Taking into account the averaging procedure over whole spectral groups we found in this first comparison between model and experiment a satisfactory agreement between them.

Introduction: In this contribution we present the results of a study of the inversion in the argon ion spectrum from an experimental determination as well as from a Collisional Radiative (CR) model. The experimental system was a hollow cathode arc and is closely related to argon ion laser tubes concerning electron densities and temperatures. We determined the population densities of the 4p upper and the 4s lower laser levels at the same time as the electron density and temperature. We used these last values in a CR-model, related to that of Fujimoto [1], but taking into account absorption of resonance radiation in a quantitative way. As more precize data on collisional cross sections of individual levels lack recently we restricted ourselves in this model study on the average behaviour of whole spectral groups. The population densities obtained from the CR-model could be compared with the experimental results within the limitations mentioned. As far as we know no direct comparison between experiment and model was available up till now. Preceeding studies of e.g. Fujimoto [1], Kiteava e.a. [2] and Coulliex and Mourier [3] are in this respect not complete; in particular a satisfactory determination of the electron density and temperature is lacking.

Model: A plasma suitable for argon ion laser action is in a typical CR situation far from LTE. We restricted ourselves in the elementary processes to the doublet system. We are not able to account for possible interactions between doublet and quartet levels for lack of data on these interactions. The spectral groups involved are 3p (groundlevels), 3d, 4s, 4p and 4d and each group is treated as one main level. The processes we took into account were mutual electronic (de)excitation between all the groups mentioned, spontaneous emission between them and absorption of resonance radiation. The influence of the absorption was introduced by means of an escapefactor as given by Klein [4]. The external parameters of the CR-model are the electron density n_e, the electron temperature T_e and the optical depth $n_e l/\sqrt{T_i}$, where l is the diameter of the plasma column and T_i is the ion temperature. The internal parameters as (de)excitation rates for the collisional processes have been calculated with the help of the data of Beigman e.a. [5], whereas the rates for the radiative processes have been determined with data of Luijken [6] and Van der Sijde [7]. The transition probability of Luijken for the 3d group differs by a factor of 20 with respect to that used by the other authors ($6{*}10^8 s^{-1}$ against $120{*}10^8 s^{-1}$). As a consequence, the role of the 3d group in our model is more important than in those of the others. The output delivered by a P9200 computer furnishes us the population densities as well as the contribution of the various processes for (de)population as functions of the electron density, electron temperature and optical depth.

Experiment: The plasma source was a d.c. hollow cathode arc discharge [8] confined by an axial magnetic field of $\leq$ 0.15 T to a diameter of about 20 mm. The electron density $n_e = (0.1-3){*}10^{19} m^{-3}$ was determined by means of Thomson scattering with a ruby laser source and a tunable 6 Å bandwidth filter as a dispersive medium. The electron temperature $T_e = (25-70){*}10^3$ K was determined with the help of the intensity of the 740 Å VUV line. This determination was calibrated with Thomson scattering for a series of conditions with small discharge currents. Under these conditions the mean result of the Thomson scattering was reliable, as background radiation was relatively small. The diameter of the plasma column was determined from Abel transformed radiation profiles and the ion temperatures $T_i = (1-20){*}10^3$ K were derived with the help of a Fabry Perot interferometer. The 4p population densities were calculated from line intensity measurements after calibration with a tungsten ribbon lamp with the help of a 0.5 m Jarell Ash monochromator. The 4s densities were calculated from VUV line intensities (718-730 Å),measured with a 0.5 m Seya Namioka type Mc. Pherson monochromator. A special Abel inversion was carried out to account for the absorption phenomena. Calibration was carried out with the help of the 740 Å line from the quartet-doublet transition $4s\,^4P_{3/2}-3p\,^2P_{3/2}$. The $4s\,^4P_{3/2}$ level is assumed to have a population density originating from visible cascade radiation of 4p quartet levels. We estimate that this process determines the $4s\,^4P_{3/2}$ density for at least 80%.

Results: The results of the measurements and calculations are presented in table 1 for a limited number of plasma conditions. We made one series as a function of the background pressure p and a second series as a function of the magnetic induction B. The relevant external parameters are listed in the table. The population densities per unit statistical weight for upper and lower laser levels both from experiment and model are also indicated. The ratio $n_{4s}g_{4p}/n_{4p}g_{4s}$ from experimental and model data is showed in fig.1 as function of the magnetic induction. As a comparison , model data without absorption of resonance radiation taking into account, are also indicated. We emphasize that this ratio is a sensitive parameter in comparing the experimental and model data.

Discussion and conclusion: We conclude that within the variation of the electron density as given in the table, the agreement between experimental and model data, concerning spectral groups as a whole, is satisfactory. The densities in our experiment were smaller than $5{*}10^{19} m^{-3}$, which value is normally found as laser threshold. Therefore and by the fact that our device is not suitable for end-on measurements, we have not tried to show laser action. The fact that inversion exists for these small densities below the normally observed threshold can be explained by the small values of $(n_{4p}/g_{4p}-n_{4s}/g_{4s})$, so that mirror losses cannot be compensated fully and no gain can be expected. The difference between experimentally determined ratios $n_{4s}g_{4p}/n_{4p}g_{4s}$ and those of the model is caused by the influence of absorption in the model, represented by the escapefactor. The influence of absorption on the experimental ratio data appears to be a factor 2 or less smaller than on the model data. This discrepancy is a little surprisingly as measurements of the ratio of two resonance lines with the same upper levels show a clear influence of absorption phenomena. We suppose that the numerical relation between the escapefactor and the optical depth is still questionable. Treatment of the experiment-model comparison for seperate levels instead of groups is in principle possible by the work of Rubin and Sobolev [9].

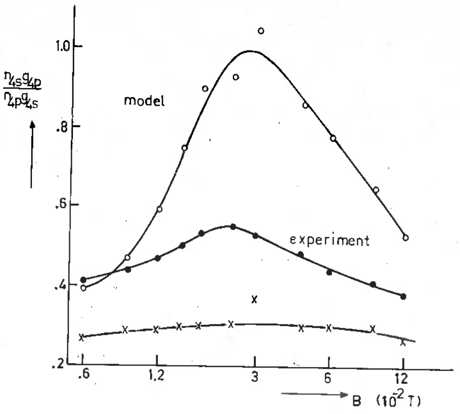

Figure 1.

Comparison of the ratio of lower and upper laser level populations per unit statistical weights as a function of the magnetic induction for experimental and model data.

I = 40 A,
p = 2 mtorr,
● = experiment,
0 = model,
x = model without absorption.

Table 1.

P,B	n_e ($10^{19}m^{-3}$)	T_e (10^3K)	$n_e l/\sqrt{T_i}$ (a.e.)	n_{4s}^{exp}/g_{4s} ($10^{13}m^{-3}$)	n_{4p}^{exp}/g_{4s} ($10^{13}m^{-3}$)	n_{4s}^{mod}/g_{4s} ($10^{13}m^{-3}$)	n_{4p}^{mod}/g_{4s} ($10^{13}m^{-3}$)
3.6mtorr	1.78	37.3	0.52	0.37	1.03	0.39	0.70
2.8 "	2.46	34.5	0.65	0.47	1.32	0.56	0.84
2.0 "	2.21	40.1	0.51	0.68	1.81	0.86	1.62
1.6 "	1.68	49.1	0.34	0.85	2.35	0.96	2.42
1.2 "	1.68	53.2	0.28	1.03	3.11	1.27	3.51
0.8 "	1.35	65.0	0.21	1.23	3.67	1.47	4.74
$6{*}10^{-2}$T	2.5	33.6	0.80	0.40	0.91	0.59	0.76
3 "	2.7	29.6	1.19	0.21	0.40	0.45	0.43
1.8 "	1.4	29.9	0.92	0.057	0.11	0.10	0.12
1.2 "	0.55	32.3	0.51	0.014	0.029	0.016	0.027
0.6 "	0.17	31.6	0.21	0.0012	0.0030	0.00089	0.0023

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