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INVESTIGATION OF LS COUPLING IN OXYGEN III

B.Blagojević, M.V.Popović, Z.Pavlović and N.Konjević
Institute of Physics, 11080 Belgrade, P.O.Box 68 Yugoslavia

INTRODUCTION

LS or Russell-Saunders coupling is dominant for many transitions in the spectra of light elements. The spin-orbit interaction in atomic Hamiltonian becomes more important in comparison to the electrostatic separation between levels of the same principal quantum number n. Electrostatic separation increases as Z while the spin-orbit interaction grows as $Z^4\alpha^2$ where α is fine structure constant, so the LS-coupling scheme becomes inappropriate at some point. Systematic failure of the LScoupling approximation is expected from lower to higher elements of an isoelectronic sequence for nl-nl' transitions. The aim of this paper is to test accordance of experimental and theoretical data for LS-coupling in O III ions (3s-3p and 3p-3d transitions).

THEORY

Theoretical values calculated from multiconfiguration Dirac-Fock (MCDF) wave function of moderate accuracy are compared with our measured intensity ratios. For the case of pure LS coupling the relative line strength for a transition between levels J and J is proportional to the factor (Cowan, 1981, Appendix I)

$$D^2 = (2J_1+1)(2J_2+1)\begin{Bmatrix} L_1 & S_1 & J_1 \\ J_2 & 1 & L_2 \end{Bmatrix} \tag{1}$$

Values of the 6j symbol are given in Appendix D of Cowan, 1981. The intensity ratio of two multiplet components is represented by (Glenzer et al.,1994)

$$\frac{I}{I'} = \frac{\lambda'^4 D^2_{line}}{\lambda^4 D'^2_{line}} e^{\frac{E'-E}{kT}} \tag{2}$$

where I, λ and I', λ' are the total intensities and wavelengths of the two components, and E and E' are the energies of the upper levels of the two components, respectively.

EXPERIMENT

The light source was a low pressure pulsed arc with quartz discharge tube 10 mm internal diameter. The distance between aluminum electrodes was 16.2 cm and 3 mm diameter holes were located at the center of both electrodes to allow end-on plasma observations to be made. The central part around the pulsed arc axis was imaged 1 : 1 onto the entrance slit of the 1-m monochromator by means of the concave 1 m focal length, focusing mirror. A 30 mm diaphragm placed in front of the focusing mirror ensures that light comes from the narrow cone about the arc axis.

The monochromator with inverse linear dispersion 0.833 nm/mm in the first order of the diffraction grating, was equipped with the photomultiplier tube (PMT) and a stepping motor. Signals from the PMT were led to a digital storage oscilloscope which was triggered by the voltage pulse from the Rogowski coil induced by the current pulse through the discharge tube. The ischarge was driven by a 15.2 μF low inductance capacitor charged to 3 KV (peak current 15 KA) and fired by an ignitron. The stepping motor and oscilloscope are controlled by personal computer which was also used for data acquisition. Recordings of spectral line shapes were performed shot-by-shot. At each wavelength position of the monochromator time evolution and decay of the plasma radiation were recorded and memorized by the oscilloscope. Eight such signals were averaged at each wavelength. Further, to construct the line profiles these averaged signals at different wavelengths and at various times of the plasma existence were used to construct line profiles. Greatest care was taken to find the optimum conditions with the least line self absorption. It was found that the percentage of oxygen in the mixture was of crucial importance for the elimination of self-absorption. The ratio O_2 : He = 0.6 : 99.4 was determined after a number of experiments in which O_2 was diluted gradually until strong line intensities O III are find proportional to the concentration of O_2 in the gas mixture. During the spectral line recording continuous flow of oxygen-helium mixture was maintained at a pressure of about 400 [Pa].

PLASMA DIAGNOSTICS

For the electron density measurements we use the width of He II P_α 468.6 nm line. The full width at half maximum $\Delta\lambda_{FWHM}$ of this line is related to the electron density N_e using the following relationship (Pittman and Fleurier, 1982; 1986; Fleurier and Le Gall, 1984)

$$N_e = 2.04 \cdot 10^{16} \cdot \Delta\lambda_{FWHM}{}^{1.21} \qquad (3)$$

where N_e is in cm^{-3} and $\Delta\lambda_{FWHM}$ in 0.1 nm units. This equation is based on the fitting of the experimental data, and in fact closely agrees with calculations by Griem and Shen, 1961. Our main concern in electron-density measurements is a possible presence of self-absorption of the 468.6 nm line which may distort the line profile. This would result in erroneous reading of the line half width which, after the use of Eq.(3), introduces an error inelectron-density measurements. There are several experimental methods which can be used for self absorption check (Konjević and W.L.Wiese, 1976) but unfortunately, none of them is convenient for the He II 468.6 nm line or for our long, pulsed plasma source. Recently, in order to determine the optical thickness of the investigated line Kobilarov et al., 1981 have introduced in the discharge an additional movable electrode. By positioning the movable electrode at two different positions and by recording the line profiles from two plasma lengths it is possible to determine $k_\lambda l$ where k_λ is the spectral line absorption coefficient and l is the plasma length along the direction of observation. If $k_\lambda l$ is not large ($k_\lambda l < 1$ (Wiese, 1965)) it is possible to recover the line profile (Fig.2 of Kobilarov et al., 1981) for the optically thin case.The same method is used here for the He II 468.6 nm line self absorption testing. For this purpose an additional aluminum electrode (10 mm thick) is located inside the discharge tube and the profiles of 468.6 nm line are recorded with two plasma lengths. Since the measured $k_\lambda l$ was smaller than 0.82 it was possible to recover the line profile for the optically thin case.

EXPERIMENTAL RESULTS AND DISCUSSION

The experimental results for intensity ratios R_m from $3s$-$(^2P^0)3p$ multiplet (I_{2-3}/I_{1-2}) and $3p$-$(^2P^0)3d$ multiplet (I_{3-4}/I_{2-3}) of O III ions are compared with theoretical ratios R_{th} given in Table 1 together with electron concentration. Theoretical ratios are $R_{th} = 1.84$ for $3s$-$(^2P^0)3p$ multiplet and $R_{th} = 1.43$ for $3p$-$(^2P^0)3d$ multiplet. Table 1 shows that LS coupling approximation is fulfilled for investigated transitions in O III ions.

Electron density N_e [10^{17} cm^{-3}]	Transition array $3s$-$(^2P^0)3p$ R_m / R_{th}	$3p$-$(^2P^0)3d$ R_m / R_{th}
0.64	1.07	1.13
1.05	1.14	1.06
1.22	0.96	1.14
1.32	1.00	1.05
1.33	0.95	0.94
1.30	1.03	1.01
1.21	0.95	0.97
1.07	0.96	0.95
0.90	0.94	0.95
0.73	0.94	0.90
0.57	0.98	1.10
0.46	0.97	1.01
0.37	0.84	1.10
	<0.98>	<1.02>

Table 1. R_m / R_{th} ratios for $3s$-$(^2P^0)3p$ and $3p$-$(^2P^0)3d$ transitions in O III. Averaged ratios for measured electron densities N_e are given in <> brackets

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