Journal of Research in Physics Vol.28, No. 3, 223-226 (1999)

EXPERIMENTAL STUDY OF LS COUPLING ALONG LITHIUM ISOELECTRONIC SEQUENCE

B.Blagojević, M.V.Popović and N.Konjević

Institute of Physics, 11080 Belgrade, P.O.Box 68, Yugoslavia

1. INTRODUCTION

LS or Russell-Saunders coupling is dominant for many transitions in the spectra of light elements. This is the case spin-orbit interaction in atomic Hamiltonian is more important than the electrostatic separation between levels of the same principal quantum number n. Since electrostatic separation increases as Z while the spin-orbit interaction grows as $z^4\alpha^2$ where z is charge number of atomic nucleus and α is fine structure constant, the LS-coupling scheme becomes inappropriate at a certain point. Systematic failure of the LS-coupling approximation is expected from lower to higher elements of an isoelectronic sequence for nl-nl' transitions. The aim of this paper is to test predictions of LS-coupling theory for the transitions within $3s^2S\text{-}3p^2P^0$ multiplets along lithium isoelectronic sequence. In addition we tested whether plasma electron density influences spontaneous emission coefficients as suggested by Chung et al, 1988.

2. THEORY

For LS coupling theory see e.g. (Cowan, 1981). Theoretical values calculated from wave function obtained using Coulomb approximation are compared with our measured intensity ratios. For the case of pure LS coupling the relative line strength for a transition between levels J_1 and J_2 is proportional to the factor (Cowan, 1981, Appendix I)

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

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

$$\frac{I}{I'} = \left(\frac{\lambda'}{\lambda}\right)^4 \left(\frac{D_{line}}{D'_{line}}\right)^2 \exp\left(\frac{E'-E}{kT_e}\right) \qquad (2)$$

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.

3. 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 discharge was driven by a 15.2 μF low inductance capacitor charged to 3.0 kV and fired by an ignitron. Greatest care was taken to find the optimum conditions with the least line self-absorption. It was found that the percentage of each studied element in the appropriate gas mixture was of crucial importance for the elimination of self-absorption. During the spectral line recording continuous flow of gas mixtures was maintained at a pressure of about 400 Pa.

4. 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 (Büscher et al, 1996)

$$N_e(cm^{-3}) = 2.238 * 10^{16}\,\Delta\lambda^{1.204}{}_{FWHM} \tag{3}$$

where $\Delta\lambda_{FWHM}$ is 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 in electron-density measurements. There are several experimental methods which can be used for self-absorption check (Konjević and 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 0.74 it was possible to recover the line profile for the optically thin case.

5. EXPERIMENTAL RESULTS AND DISCUSSION

The theoretical intensity ratios R_{th} of two most intensive ion spectral lines within $3s^2S$-$3p^2P^0$ multiplets of B III, C IV, N V and O VI ions of lithium isoelectronic sequence are given in Table 1. R_{th} are calculated from wave functions obtained in Coulomb approximation. The experimental intensity ratios R_m of two most intensive ion spectral lines within $3s^2S$-$3p^2P^0$ multiplets of B III, C IV, N V and O VI ions are compared with appropriate theoretical intensity ratios in Table 2. The R_m values are averaged over set of measurements which corresponding different electron concentrations N_e in plasma.

Table 1.

Transition	R_{th}
B III $3s^2S$-$3p^2P^0$	2.00
C IV $3s^2S$-$3p^2P^0$	2.01
N V $3s^2S$-$3p^2P^0$	2.03
O VI $3s^2S$-$3p^2P^0$	2.05

The agreement between averaged $<R_m>$ and theoretical R_{th} ratios along lithium isoelectronic sequence in Table 2 is within ±6% which is under estimated relative experimental error of ±10%. Table 2 is good indication that theory [8] predicts well spectral line intensity ratios within multiplets in case of C IV, N V and O VI emitters. Within the investigated plasma electron density range spontaneous emission coefficients remain constant what is in agreement with results and discussion in Refs.[9-10].

Table 2.

Ion	N_e [10^{17}cm^{-3}]	$\left(\frac{R_m}{R_{th}}\right)_{3s-3p}$
B III	0.28	0.99
	0.58	0.99
		<0.99>
C IV	0.58	0.93
	0.76	0.96
	0.86	0.94
		<0.94>
N V	0.86	0.93
	0.99	1.02
	1.13	1.06
	1.21	1.02
	1.33	0.92
		<0.99>
O VI	1.09	1.01
	1.38	1.00
	1.41	0.96
	1.57	0.94
	1.68	0.97
		<0.98>

REFERENCES

Chung Y., Lemaire P. and Sucewer S.:1988, Phys.Rev.Lett. **60**, 1122.

Cowan R.D.:1981, *The Theory of Atomic Structure and Spectra*, University of California Press, Berkeley.

Büscher S., Glenzer S., Wrubel Th. and Kunze H.-J.:1996, J.Phys.B, **29**, 4107.

Griem H.R. and Shen K.Y.: 1961, Phys.Rev. **122**, 1490.

Konjević N. and Wiese W.L.:1976, J.Phys. Chem. Ref. Data **5**, 259.

Kobilarov R., Konjević N. and Popović M.V.:1981, Phys.Rev.A **40**, 3871.

Wiese W.L.:1965, in *Plasma Diagnostic Techniques*, eds. by Huddleston R.M. and Leonard S.L., Academic, New York.

Wiese W.L., Fuhr J.R. and Deters T.M.:1996, *Atomic Transition Probabilities of Carbon, Nitrogen and Oxygen*, J.Phys.Chem.Ref.Data Monograph No.7.

Griem H.R., Huang Y.W., Wang J.-S. and Moreno J.C.:1991, Phys.Fluids B **3** 2430.

Griem H.R.:1991, Phys.Rev.Lett. **66**, 521.