The Study of \(3s^3p^4\) Configuration in the P-Sequence, Co XIII - Ni XIV, by Laser-Produced Plasmas

F. O. Borges*, G. H. Cavalcanti, E. E. Farias, and A. G. Trigueiros
Instituto de Física, Universidade Federal Fluminense, UFF
Campus da Praia Vermelha-Gragoatá, 24210-340 Niterói, Rio de Janeiro, Brazil

Received on 17 November, 2006

Wavelengths from radiation of plasmas produced by a Nd:YAG/glass laser focused on target of Co and Ni have been recorded photographically in the region 240-600 Å with a 3m normal incidence spectrograph. For this sequence (Co XIII and Ni XIV) we have identified 13 new lines belonging to the array \(3s^3p^3\)-\(3s^3p^4\) and derived 7 new levels for the \(3s^3p^4\) configuration. The classification was established by comparison of the relative intensities for the lines along the isoelectronic sequence, extrapolation, and Hartree-Fock calculation.

Keywords: Co XIII spectrum; Ni XIV spectrum; Laser-produced plasmas

I. INTRODUCTION AND EXPERIMENT

The ground configuration of the P-like system is \(3s^23p^3\) and has \(5s_0\) for the lowest energy level. For this sequence the spectra from P I to Fe XII are known[1] for the configuration \(3s^3p^4\). For more higher ionized ion in the P-isoelectronic sequence, no information was available. The purpose of this work is to study the energy levels structure of the \(3s^3p^4\) configuration in the P-sequence, Co XIII and Ni XIV.

We used the plates from an early experiment made by Litzen and Redfors.[2-3] In the same plates were presented wavelengths from radiation of plasmas produced by a Nd:YAG/glass laser focused on target of Co and Ni. The energy of the pulses was 4J to Co and Ni and had a duration of 3 nsec. A 3 m normal incidence spectrograph, with a grating of 1200 grooves/mm was used to record the radiation emitted by the plasma in a direction parallel to the target plane and perpendicular to the main direction of the plasma expansion, thus minimizing the Doppler effect from plasma mass motion. Spectra were recorded on Kodak 101 plates in the region 240-600 Å. The plate factor was 2.7 Å/mm. The estimated uncertainty of the wavelengths is about ± 0.05 Å.

II. WAVELENGTHS AND ENERGY LEVELS

In table 1 and 2 we show the wavelengths and energy levels for the Co XIII and Ni XIV ions in the phosphorus. We have studied the transitions \(3s^23p^3\)-\(3s^3p^4\) in both ions and determined the energy levels in the \(3s^3p^4\) configuration. The classification of the lines was based on Hartree-Fock calculations and for this purpose we have used the Cowan’s[5] computer code. In Fig. 1 we can see the extrapolation of the experimental energy level values from Ca VI to Ni XIV using the Edlén’s[6] method. This method was also used to help the classification of the lines. The zero level in the figure 1 is the \(3s^23p^2\ 2D^2_3/2\) level from the ground configuration. The net core charge is represented by \(\zeta\) and 1.0 is a constant determined from the experimental energy levels in the extrapolation so that we can get a good smooth of the curve in the Fig. 1.

In an early analysis made by Fawcett and Hayes[7] some lines and energy levels were determined. In the present work we have classified 13 new lines belong the transition \(3s^23p^3\)-\(3s^3p^4\) and located 7 new levels to the \(3s^3p^4\) configuration. The transition \(3s^23p^3\ 4S^2_3/2\) to \(3s^3p^4\ 4P^2_3/2\) at 316.53 Å in Ni XIV was classified by Fawcett and Hayes[7] but instead we present a new line at 316.12 Å. This new line is in agreement with our extrapolation and relative intensities along the isoelectronic sequence. We determined all levels for the \(3s^3p^4\) configuration in Co XIII and Ni XIV.

The results of calculations made by Huang[8] and Biémont[9] were available in the analysis of data from P-sequence.
TABLE II: Energy levels of phosphoruslike Co XIII and Ni XIV

| LEVEL DESIGNATION | Co XIII | Ni XIV |
|-------------------|---------|--------|
| $3s^3p^4 \quad ^2P_S/2$ | 295142 $^a$ | 316336 $^a$ |
| $3s^3p^4 \quad ^2P_P/2$ | 307040 $^b$ | 333819 $^b$ |
| $3s^3p^4 \quad ^4P_1/2$ | 311983 $^a$ | 336757 $^a$ |
| $3s^3p^4 \quad ^2D_3/2$ | 365852 $^a$ | 393319 $^a$ |
| $3s^3p^4 \quad ^2D_S/2$ | 368214 $^b$ | 395484 $^a$ |
| $3s^3p^4 \quad ^2P_3/2$ | 418491 $^b$ | 447796 $^b$ |
| $3s^3p^4 \quad ^2P_1/2$ | 423305 $^b$ | 452823 $^b$ |

$^a$New level; $^b$Previous identified by Fawcett and Hayes, See Ref.7.

FIG. 1: Isoeletronic comparison in phosphoruslike ions of the $3s^3p^4$ experimental energy levels. The energy level of $3s^23p^3\quad ^2D_O/2$ of the ground configuration is set to zero.

Acknowledgements

This work has been supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico, CNPq (Brazil) and Swedish Natural Science Research Council, NFR (Sweden). F. O. Borges, thanks Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro, FAPERJ (Brazil), for a fellowship.

[1] R. L. Kelly, J. Phys. Chem. Ref. Data 16, 298 (1987).
[2] U. Litzén and A. Redfors, Phys. Scr. 36, 895 (1987).
[3] A. Redfors and U. Litzén, J. Opt. Soc. Am. B 6, 1447 (1989).
[4] A. G. Trigueiros, F. O. Borges, G. H. Cavalcanti, and E. E. Farias, J. Quant. Spectrosc. Radiat. Transfer 97, 29 (2006).
[5] R. D. Cowan, The Theory of Atomic Structure and Spectra, Berkeley: Univ. California Press (1981).
[6] B. Edlén, Atomic Spectra in Encyclopedia of Physics, Edited by S. F. Flügge (Springer-Verlag, Berlin) vol. XXVI, 80(1984).
[7] B. C. Fawcett and R. W. Hayes, J. Phys. B 5, 366 (1972).
[8] K. N. Huang, Energy-Level Scheme and Transition-Probabilities of P-Like Ions, At. Data. Nucl. Data Tables 30, 313 (1984).
[9] E. Biémont, Phys. Scr. 33, 324 (1986).