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## The Study of $3s3p^4$ Configuration in the P-Sequence, Co XIII - Ni XIV, by Laser-Produced Plasmas

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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  $3s^23p^3$ - $3s3p^4$  and derived 7 new levels for the  $3s3p^4$  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  $3s3p^4$ . 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  $3s3p^4$  configuration in the P-sequence, Co XIII and Ni XIV.

We used the plates from an early experiment made by Litzén and Redfors.[2-3] In the same plates were presented lines from a recent work by Trigueiros et al.[4] The spectra were obtained by focusing high-power pulses from a Quantel NG 24 Nd:YAG/glass laser into metal targets of the elements 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 recorder 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  $\pm 0.05$  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  $3s^23p^3$ - $3s3p^4$  in both ions and determined the energy levels in the  $3s3p^4$  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  $3s^23p^2 \ ^2D_{5/2}^0$  level from the ground configuration. The net core charge is represented by  $\zeta$  and 1.0 is a constant de-

TABLE I: Observed wavelengths for transitions in phosphoruslike Co XIII and Ni XIV

TRANSITION	Co XIII $\lambda(\text{\AA})$	Ni XIV $\lambda(\text{\AA})$
$3s^23p^3 \ ^2D_{3/2}^0 - 3s3p^4 \ ^2P_{1/2}$	263.40 <sup>b</sup>	245.67 <sup>a</sup>
$3s^23p^3 \ ^2D_{3/2}^0 - 3s3p^4 \ ^2P_{3/2}$	-	248.74 <sup>a</sup>
$3s^23p^3 \ ^2D_{5/2}^0 - 3s3p^4 \ ^2P_{3/2}$	271.15 <sup>b</sup>	253.66 <sup>b</sup>
$3s^23p^3 \ ^2P_{1/2}^0 - 3s3p^4 \ ^2P_{1/2}$	-	271.96 <sup>a</sup>
$3s^23p^3 \ ^2D_{3/2}^0 - 3s3p^4 \ ^2D_{3/2}$	310.34 <sup>a</sup>	288.88 <sup>a</sup>
$3s^23p^3 \ ^2D_{5/2}^0 - 3s3p^4 \ ^2D_{5/2}$	313.95 <sup>b</sup>	292.47 <sup>a</sup>
$3s^23p^3 \ ^2D_{5/2}^0 - 3s3p^4 \ ^2D_{3/2}$	316.29 <sup>a</sup>	-
$3s^23p^3 \ ^4S_{3/2}^0 - 3s3p^4 \ ^4P_{1/2}$	320.53 <sup>a</sup>	296.95 <sup>a</sup>
$3s^23p^3 \ ^4S_{3/2}^0 - 3s3p^4 \ ^4P_{3/2}$	325.69 <sup>b</sup>	302.28 <sup>b</sup>
$3s^23p^3 \ ^4S_{3/2}^0 - 3s3p^4 \ ^4P_{5/2}$	338.82 <sup>b</sup>	316.12 <sup>a</sup>
$3s^23p^3 \ ^2P_{1/2}^0 - 3s3p^4 \ ^2D_{3/2}$	349.19 <sup>a</sup>	325.92 <sup>a</sup>
$3s^23p^3 \ ^2P_{3/2}^0 - 3s3p^4 \ ^2D_{5/2}$	357.08 <sup>a</sup>	-
$3s^23p^3 \ ^2P_{3/2}^0 - 3s3p^4 \ ^2D_{3/2}$	360.15 <sup>a</sup>	-

<sup>a</sup>New line; <sup>b</sup>Previous identified by Fawcett and Hayes, See Ref.7.

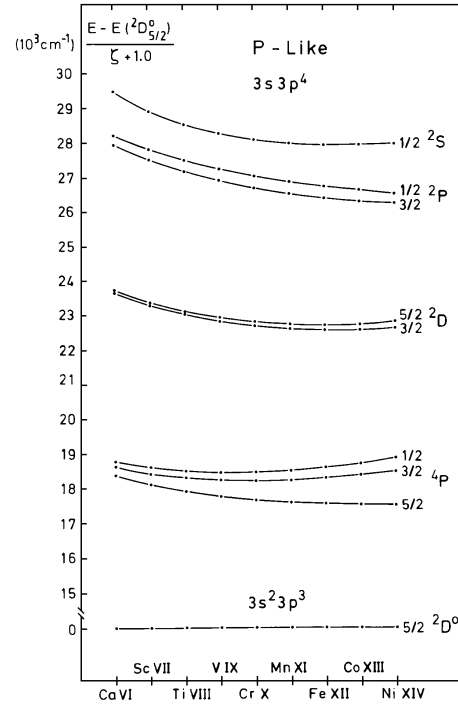
termined from the experimental energy levels in the extrapolation so that we can get a good smooth of the curve in the Fig. 1.

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 array  $3s^23p^3$ - $3s3p^4$  and located 7 new levels to the  $3s3p^4$  configuration. The transition  $3s^23p^3 \ ^4S_{3/2}^0$ - $3s3p^4 \ ^4P_{5/2}$  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  $3s3p^4$  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
		$cm^{-1}$	$cm^{-1}$
$3s3p^4$	$4P_{5/2}$	295142 <sup>b</sup>	316336 <sup>a</sup>
$3s3p^4$	$4P_{3/2}$	307040 <sup>b</sup>	330819 <sup>b</sup>
$3s3p^4$	$4P_{1/2}$	311983 <sup>a</sup>	336757 <sup>a</sup>
$3s3p^4$	$2D_{3/2}$	365852 <sup>a</sup>	393319 <sup>a</sup>
$3s3p^4$	$2D_{5/2}$	368214 <sup>b</sup>	395484 <sup>a</sup>
$3s3p^4$	$2P_{3/2}$	418491 <sup>b</sup>	447796 <sup>b</sup>
$3s3p^4$	$2P_{1/2}$	423305 <sup>b</sup>	452823 <sup>a</sup>

<sup>a</sup>New level; <sup>b</sup>Previous identified by Fawcett and Hayes, See Ref.7.FIG. 1: Isoelectronic comparison in phosphoruslike ions of the  $3s3p^4$  experimental energy levels. The energy level of  $3s^2 3p^3 \ 2D_{5/2}^0$  of the ground configuration is set to zero.

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