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ABSTRACT

Using a grazing-incidence spectrometer and a low inductance, 14μF, 12-17 kV, spark source, the authors have observed spectra of Sc XII, Ti XIII, and V XIV. The lines have been identified as arising from transitions between the ground level $2s^2 2p^6\ {}^1S_0$ and the following electronic configurations: $2s\ 2p^6\ 3p$, and $2s^2\ 2p^5\ 4s$, 4d, 5d. The transitions of the type $2s^2\ 2p^6 - 2s^2\ 2p^5\ 4d$ have been observed also in Co XVIII Ni XIX and Cu XX.

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It is generally evident on considering an isoelectronic sequence of ions that as one proceeds to higher degrees of ionization the number of known levels decreases. One of the important reasons for this situation, especially for the very high degrees of ionization (above the 10th, say), is the lack of a suitable source for generating the spectra with reasonable intensity. In the Ne I isoelectronic sequence energy levels have been identified as far as Zn XXI. Edlén and Tyrén (1936) treated the following ions: K IX, Ca XI, Sc XII, Ti XIII, and V XIV. The spectra of Cr XV, Mn XVI, Fe XVII, and Co XVIII were reported by Tyrén (1938). Fawcett (1965) measured some levels of Sc XII, Ti XIII and V XIV, Feldman, Cohen, and Swartz (1967) extended the isoelectronic sequence to Ni XIX, Cu XX, and Zn XXI. Until recently, a noticeable gap in the Ne I isoelectronic sequence existed for the spectra of Sc XII, Ti XIII, and V XIV where only the following levels had been identified: $2s^2\ 2p^6\ {}^1S_0$, $2s^2\ 2p^5\ 3s\ {}^3P^o_1$, ${}^1P^o_1$, and $2s^2\ 2p^5\ 3d\ {}^3P^o_1$, ${}^3D^o_1$, ${}^1P^o_1$ (the $2s^2\ 2p^5\ 3d\ {}^3P^o_1$ level in V XIV not being known). For ions below Sc XII, and above V XIV, the number of known levels is usually greater. This gap was probably due to the fact that the experimental methods by which the Sc, Ti and V ions were first investigated (Edlén and Tyrén, 1936) were inadequate to obtain high intensities in this region. Therefore, only the most intense lines were observed. Later when Tyrén (1938) treated the ions from Cr xv to Co xviii with improved methods and identified a greater number of energy levels, he did not return to the Sc, Ti and V ions.

Fawcett (1965), using a two-meter grazing incidence spectrometer and a 600 lines per mm Bausch and Lomb blazed replica grating, with a 1/2μF, 90 kV vacuum spark source, recorded lines of Sc, Ti and V. He classified three lines each of Sc xii and Ti xiii, and four lines of V xiv belonging to transitions from the following configurations: $2p^6$-$2s\ 2p^6\ 3p$ and $2p^6$-$2p^5\ 4d$. He also reports an additional line in V xiv classified as follows: $2p^6$-$2p^5\ 3d$. His wavelength measurements are reported to an accuracy of ±0.02Å.

Independently, we recorded spectra in this region by using a modified Jarrell-Ash 3-meter grazing-incidence spectrometer, with a Bausch and Lomb 1200 lines per mm blazed gold replica. Our source was a 14μF, 12 to 17 kV, low-inductance condensed spark. As reference for wavelength calibration we used carbon and oxygen lines, and known lines of the same element isoelectronic with Ne I (Moore, 1949, 1952). We have observed spectra of Sc xii, V xiii, Ti xiv, Co xviii, Ni xix and Cu xx. As well as the lines arising from transitions between the $2s^2\ 2p^6$ and $2s^2\ 2p^5\ 3s$, 3d electronic configurations, the lines arising from transitions between the following configurations

were recorded for Sc XII, V XVIII and Ti XIV:
$2s^2\ 2p^6$-$2s\ 2p^6\ 3p$, and $2s^2\ 2p^6$-$2s^2\ 2p^5\ 4s$, $4d$, $5d$. The wavelengths, energies, and visually estimated intensities are summarized in Table 1. Term values are given in Table 2. The line belonging to $2s^2\ 2p^6\ {}^1S_0$ - $2s^2\ 2p^5\ 3d\ {}^3P_1^0$ in V XIV is also included. The wavelengths in Table 1 were measured to an accuracy of better then ±0.005Å. For Co XVIII Ni XIX and Cu XX transitions of the type $2s^2\ 2p^6$-$2s^2\ 2p^5\ 4d$ have been measured to an accuracy of ±0.01Å. The wavelengths and energies are in Table 3.

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TABLE 1 - Classified lines from the $2s^2\,2p^6$ - $2s\,2p^6\,3p$ and $2s^2\,2p^6$ - $2s^2\,2p^5$ 3d, 4s, 4d, 5d transitions of Sc xii, Ti xiii and V xiv

Transitions	Sc xii λ(Å)	Sc xii Int	Sc xii (cm^{-1})	Ti xiii (Å)	Ti xiii Int	Ti xiii ν(cm^{-1})	V xiv λ(Å)	V xiv Int	V xiv ν(cm^{-1})
$2s^2 2p^6\ {}^1S_0$ - $2s^2\,2p^5\,3d\ {}^3P^0_1$							21.294	10	4691000
" $2s\,2p^6\,3p\ {}^3P^0_1$	23.821	1	4198000	21.127	2	4733300	18.870	3	5299400
" $2s^2\,2p^5\,3p\ {}^1P^0_1$	23.725	7	4215000	21.035	7	4754000	18.783	7	5324200
" $2s^2\,2p^5\,4s\ {}^3P^0_1$	23.045	1	4339300	20.135	1	4966500	17.754	1	5632500
" $2s^2\,2p^5\,4s\ {}^1P^0_1$	22.837	1	4378800	19.943	1	5014300	17.575	1	5689900
" $2s^2\,2p^5\,4d\ {}^3D^0_1$	22.119	4	4521000	19.366	4	5163700	17.094	4	5850000
" $2s^2\,2p^5\,4d\ {}^1P^0_1$	21.940	5	4557900	19.204	5	5207200	16.939	5	5903500
" $2s^2\,2p^5\,5d\ {}^3D^0_1$	20.438	1	4892800	17.869	1	5596300	15.748	1	6350000
" $2s^2\,2p^5\,5d\ {}^1P^0_1$	20.298	2	4926600	17.727	2	5641100	15.609	2	6406600

TABLE 2 - Energy scheme for terms in Sc xıı, Ti xııı, and V xıv

Configuration	Designation	J	Sc xıı (cm^{-1})	Ti xııı (cm^{-1})	V xıv (cm^{-1})
$2s^2\ 2p^5\ 3d$	$3d\ ^3P^0$	1			4696100
$2s\ 2p^6\ 3p$	$3p\ ^3P^0$	1	4198000	4733300	5299400
$2s\ 2p^6\ 3p$	$3p\ ^1P^0$	1	4215000	4754000	5324200
$2s^2\ 2p^5\ 4s$	$4s\ ^3P^0$	1	4339300	4966500	5632500
$2s^2\ 2p^5\ 4s$	$4\ ^1P^0$	1	4378800	5014300	5689900
$2s^2\ 2p^5\ 4d$	$4d\ ^3D^0$	1	4521000	5163700	5850000
$2s^2\ 2p^5\ 4d$	$4d\ ^1P^0$	1	4557900	5207200	5903500
$2s^2\ 2p^5\ 5d$	$5d\ ^3D^0$	1	4892800	5596300	6350000
$2s^2\ 2p^5\ 5d$	$5d\ ^1P^0$	1	4926600	5641100	6406600

TABLE 3 - Classified lines from the $2s^2\ 2p^6 - 2s^2\ 2p^5\ 4d$ transitions of Co xviii, Ni xix and Cu xx

Transitions	Co xviii		Ni xix		Cu xx	
	λ(Å)	υ(cm^{-1})	λ(Å)	υ(cm^{-1})	λ(Å)	υ(cm^{-1})
$2s^2\ 2p^6\ {}^1S_0 - 2s^2 2p^5 4d\ {}^3D_1^0$	11.10	9009000	10.10	9901000	9.23	10834000
" $2s^2 2p^5\ 4d\ {}^1P_1^0$	10.97	9116000	9.97	10030000	9.11	10977000

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