$2s^22p^5$-$2s2p^6$ transitions in the fluorinelike ions Sr^{29+} and Y^{30+}

Joseph Reader
National Bureau of Standards, Washington, D. C. 20234
(Received 19 February 1982)

The $2s^22p^5$-$2s2p^6$ transitions in Sr^{29+} and Y^{30+} have been observed by means of a laser-produced plasma and a 2.2-m grazing-incidence spectrograph. Comparison of the observed $2s^22p^5\,{}^2P_{3/2\text{-}1/2}$ fine-structure intervals with values calculated by the Dirac-Fock method allows accurate wavelengths to be predicted for the $2s^22p^5\,{}^2P_{3/2}$-${}^2P_{1/2}$ magnetic-dipole transitions in the isoelectronic series of ions Kr^{27+}-Mo^{33+}.

The observation of Doppler broadening for transitions within the ground configurations of atomic ions has become an important tool for the diagnosis of fusion plasmas in tokamak reactors.[1] One such transition that has been used is the $2s^22p^5\,{}^2P_{3/2}$-${}^2P_{1/2}$ magnetic-dipole transition in the fluorinelike ions Sc^{12+}-Cu^{20+} (Refs. 2–5). However, it is expected that in future reactors these elements will be almost completely ionized so that the primary diagnostic elements will have to be of a higher atomic number.[6] It is thus important to establish wavelengths for this magnetic-dipole transition in heavier elements.

In this paper we report observed wavelengths for the $2s^22p^5$- $2s2p^6$ transitions in Sr^{29+} and Y^{30+}. By comparing these wavelengths with values calculated with the Dirac-Fock method we obtain accurate predicted wavelengths for the $2s^22p^5\,{}^2P_{3/2}$-${}^2P_{1/2}$ transition in the ions from Kr^{27+} to Mo^{33+}.

The spectra were excited in a laser-produced plasma at the Los Alamos National Laboratory. The laser was a Nd:glass system with wavelength 1.06 μm. Typical laser pulses had an energy of 30 J and a duration of 300 ps. The spectra were recorded with a 2.2-m grazing-incidence spectrograph at an angle of incidence of 87.5°. The grating had 1200 lines/mm; the plate factor at 50 Å was 0.44 Å/mm. Six laser shots were used for each spectrum. Wavelength calibration was obtained from laser-produced

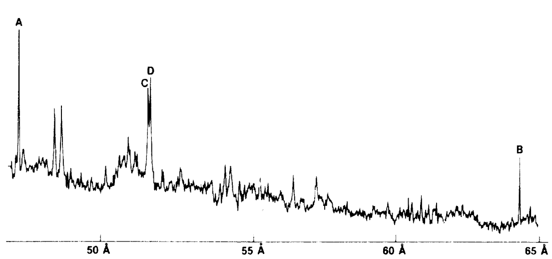

FIG. 1. Densitometer tracing of spectra of highly ionized Sr in the region 45–65 Å. A, $2s^22p^5\,{}^2P_{3/2}$-$2s2p^6\,{}^2S_{1/2}$ of Sr^{29+}; B, $2s^22p^5\,{}^2P_{1/2}$-$2s2p^6\,{}^2S_{1/2}$ of Sr^{29+}; C, $4f\,{}^2F_{5/2}$-$5g\,{}^2G_{7/2}$ of Sr^{27+}; D, $4f\,{}^2F_{7/2}$-$5g\,{}^2G_{9/2}$ of Sr^{27+}.

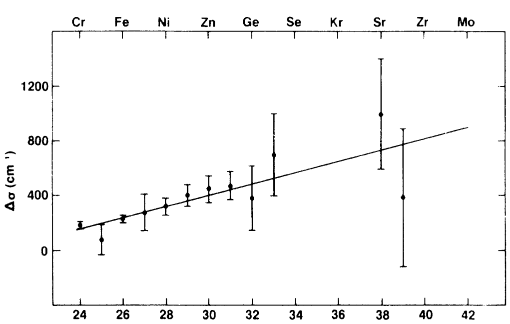

FIG 2. Differences between observed values of the $2s^22p^5\,{}^2P_{3/2}$ -${}^2P_{1/2}$ fine-structure interval in the fluorine isoelectronic sequence and the Dirac-Fock values of Cheng, Kim, and Desclaux, Ref. 9. Observed values for ions from $Z=24-32$ are taken from Refs. 5 and 10. Observed values for Sr ($Z=38$) and Y ($Z=39$) are from the present experiment.

TABLE I. Observed wavelengths in Å for the $2s^22p^5$-$2s2p^6$ transitions of Sr^{29+} and Y^{30+}.

Transition	Sr^{29+}	Y^{30+}
$2s^22p^5\,^2P_{3/2}$-$2s2p^6\,^2S_{1/2}$	47.031	44.496
$2s^22p^5\,^2P_{1/2}$-$2s2p^6\,^2S_{1/2}$	64.189	62.107

TABLE II. $2s^22p^5$ and $2s2p^6$ energy levels in cm^{-1} for Sr^{29+} and Y^{30+}.

Config.	Term	J	Sr^{29+}	Y^{30+}
$2s^22p^5$	^2P	3/2	0	0
		1/2	568 360±400	637 270±500
$2s2p^6$	^2S	1/2	2 126 300±700	2 247 400±700

spectra of Fe^{15+}-Fe^{20+}.

A densitometer trace of the spectrum of Sr in the 45–65-Å region is shown in Fig. 1. The lines of Sr^{29+}, which were identified with the aid of isoelectronic formulas of Edlén,[7] are readily seen. In Y^{30+} the $2s^22p^5\,^2P_{3/2}$-$2s2p^6\,^2S_{1/2}$ transition is clearly visible, but the $2s^22p^5\,^2P_{1/2}$ -$2s2p^6\,^2S_{1/2}$ transition is very weak and difficult to measure.

The wavelengths measured for Sr^{29+} and Y^{30+} are given in Table I. The estimated uncertainty of the absolute wavelengths is ± 0.015 Å. The uncertainty of the relative wavelengths is estimated to be ±0.010 Å for Sr^{29+} and ±0.013 Å for Y^{30+}.

The energy levels are given in Table II. The value of 637 270±500 cm^{-1} for the ^2P fine-structure interval in Y^{30+} may be compared with the values 621 000 and 616 000 cm^{-1} obtained by Boiko *et al.*[8] from two pairs of $2p^5$-$2p^43d$ transitions at about 5 Å.

In Fig. 2 we plot the differences between the observed values of the $2s^22p^5\,^2P_{3/2-1/2}$ interval and the Dirac-Fock values calculated by Cheng, Kim, and Desclaux.[9] The differences exhibit an approximately linear variation with atomic number. We adopt values for the differences in the ions from Kr^{27+} to Mo^{33+} as given by the indicated line. The resultant ^2P intervals and $^2P_{3/2}$-$^2P_{1/2}$ transition wavelengths are given in Table III. The values predicted by Edlén[10] are also listed here.

TABLE III. Predicted values of the $2s^22p^5\,^2P$ fine-structure interval $\Delta(^2P)$ in cm^{-1} and the $2s^22p^5\,^2P_{3/2}$ - $^2P_{1/2}$ transition wavelength $\lambda(^2P)$ in Å for the isoelectronic ions from Kr^{27+} to Mo^{33+}.

Ion	$\Delta(^2P)$ DF[a]	Corr[b]	$\lambda(^2P)$ Present[c]	Present[d]	Edlén[e]
Kr^{27+}	445 825	446 500±400		223.96±0.20	223.72±0.05
Rb^{28+}	503 798	504 520±400		198.21±0.16	197.95±0.05
Sr^{29+}	567 364	568 120±400	175.95±0.12	176.02±0.12	175.75±0.05
Y^{30+}	636 897	637 700±500	156.92±0.12	156.81±0.12	156.54±0.05
Zr^{31+}	712 784	713 630±600		140.13±0.12	139.85±0.05
Nb^{32+}	795 425	796 320±600		125.58±0.09	125.30±0.05
Mo^{33+}	885 244	886 180±600		112.84±0.08	112.57±0.05

[a] Dirac-Fock value of Cheng, Kim, and Desclaux, Ref. 9.
[b] Dirac-Fock value, Ref. 9, corrected according to Fig. 2.
[c] Value implied by measured value of ^2P interval.
[d] Corrected Dirac-Fock values obtained from Fig. 2 and adopted as most accurate.
[e] Value predicted by Edlén, Ref. 10, by isoelectronic extrapolation.

ACKNOWLEDGMENTS

The spectra were recorded at the Los Alamos National Laboratory with G. Luther. The cooperation of Los Alamos staff members J. McNally, R. Godwin, and A. Engelhardt is greatly appreciated. Thanks are also due to K. T. Cheng for the private communication of the Dirac-Fock results for ions not included in Ref. 9 and to U. Feldman for a stimulating discussion.

[1]S. Suckewer and E. Hinnov, Phys. Rev. Lett. 41, 756 (1978).

[2]S. Suckewer and E. Hinnov, Phys. Rev. A 20, 578 (1979).

[3]S. Suckewer, R. Fonck, and E. Hinnov, Phys. Rev. A 21, 924 (1980).

[4]E. Hinnov and S. Suckewer, Phys. Lett. 79A, 298 (1980).

[5]E. Hinnov, S. Suckewer, S. Cohen, and K. Sato, Phys. Rev. A 25, 2293 (1982).

[6]H. Hinnov, Bull. Am. Phys. Soc. 26, 811 (1981).

[7]B. Edlén, Phys. Scr. 22, 593 (1980).

[8]V. A. Boiko, S. A. Pikuz, A. S. Safronova, and A. Ya Faenov, J. Phys. B. 11, L503 (1978).

[9]K. T. Cheng, Y.-K. Kim, and J. P. Desclaux, At. Data Nucl. Data Tables 24, 111 (1979). Values for Ga^{22+}, Ge^{23+}, As^{24+}, Se^{25+}, Br^{26+}, Rb^{28+}, Sr^{29+}, Y^{30+}, and Zr^{31+} were communicated privately by K. T. Cheng (1981).

[10]B. Edlén, Opt. Pura y Apl. 10, 123 (1977).