Transitions of the type 2*s*–2*p* in fluorinelike and oxygenlike As, Se, Br, and Rb

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Transitions of the type 2*s*–2*p* in the F I and O I isoelectronic sequences of arsenic, selenium, bromine, and rubidium have been identified in spectra from laser-produced plasmas. Wavelengths in the range 50 to 90 Å were measured to an accuracy of 0.01 Å or better. The wavelengths of the magnetic-dipole transitions within the ground configurations are predicted.

INTRODUCTION

Transitions of the type 2*s*–2*p* in highly charged ions in the F I isoelectronic sequence have been identified in the spectra from laser-produced plasmas by Kononov *et al.*[1] (for the elements Cu through As) and by Reader[2] (for Sr and Y). Based on these measurements, Edlén[3] has calculated accurate wavelengths for all the elements in the F I isoelectronic sequence up to Mo ($Z = 42$). Edlén's compilation also includes recommended wavelengths for 2*s*–2*p* transitions in the O I isoelectronic sequence for the elements up to Kr ($Z = 36$) and for Mo.

We have previously reported[4,5] the measurement of wavelengths for 2*s*–2*p* transitions in the elements Cu through Ge. In this paper, we present wavelengths for the F I and O I isoelectronic sequences of As, Se, Br, and Rb. The spectra were produced by the spherical irradiation of solid targets at the University of Rochester OMEGA laser facility.

Based on the measured wavelengths for the 2*s*–2*p* transitions, the predicted wavelengths for the magnetic-dipole transitions within the ground configurations of the F-like and O-like ions are also presented. These longer-wavelength transitions are useful for the diagnosis of tokamak plasmas.[6]

EXPERIMENTAL RESULTS

The experimental conditions were similar to those in our previous experiments.[5] The targets were spherically irradiated with an approximately cubic array of six beams from the OMEGA laser system. The laser was frequency tripled (351 nm), and for each laser shot the energy incident on target was between 330 and 400 J with a pulse duration of 600 psec. Each laser beam was focused by an $f/3.7$ lens to a point a distance of 8 target radii beyond the center of the target. The average intensity of 351-nm light at the target surface was 3×10^{14} W/cm^2. The overall absorption of laser energy by the target was 70 to 90%.

The targets were mounted on glass stalks using a silicon-based adhesive. The solid pellets of pure Se were approximately spherical in shape with a diameter of 400 μm. The crystals of GaAs and RbBr were 400 μm in size.

The spectra were recorded by a 3-m grazing-incidence (88°) spectrograph that has been described in detail in Ref. 7. The spectrograph was fitted with a 1200-line/mm gold-coated Bausch & Lomb replica grating that was blazed at 127 Å. Spectral data in the wavelength region 20 to 400 Å were recorded on Kodak 101 plates. For each of the target materials (Se, GaAs, and RbBr), the spectra from two or three laser shots were accumulated onto one photographic plate. In order to distinguish the Rb and Br spectral lines on the RbBr plate, additional spectra from KBr and NaBr targets were accumulated onto a limited region of the plate by use of a slotted shutter. The Ga and As lines were distinguished on the GaAs plate by comparison with our previous spectra[5] from Ga-coated glass microballoons.

Wavelengths were determined by comparison of line positions in the second, third, fourth, and fifth orders with the positions of lines from O and Si appearing near the edge of the plate. These probably originated from the glass stalks holding the targets. These averaged wavelengths were then used to adjust the first- and second-order wavelengths. The wavelength of each line was then averaged over all orders in which it appeared. The accuracy of most wavelengths given

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Table 1. Classification of Lines Isoelectronic with F I and O I (in angstroms)[a]

Transition		Int	λ_{meas}	λ_{pred}	Int	λ_{meas}	λ_{pred}	Int	λ_{meas}	λ_{pred}	Int	λ_{meas}	λ_{pred}
F I			As XXV			Se XXVI			Br XXVII			Rb XXIX	
$2s^22p^5\,^2P_{3/2}$–$2s2p^6$	$^2S_{1/2}$	40	62.250	62.258	20	58.828	58.837	100	55.613	55.619	60	49.728	49.732
$^2P_{1/2}$	$^2S_{1/2}$	25	76.699	76.704	10	73.866	73.867	80	71.200	71.215	35	66.376	66.392
O I			As XXVI			Se XXVII			Br XXVIII			Rb XXX	
$2s^22p^4\,^3P_2$–$2s2p^5$	$^1P_1$	2	50.949	50.952				2	44.84	44.856			
$^1D_2$	$^1P_1$	20	63.027	63.051	9	59.869	59.883	40	56.840	56.862	12	51.20	
$^3P_2$	$^3P_1$	9	64.442	64.447	7	60.571	60.577	30	56.970	56.979	13	50.52	
$^3P_1$	$^3P_0$	14	69.659	69.650	4	65.69	65.674	11	61.931	61.934	35	55.143	
$^3P_2$	$^3P_2$	16	71.196	71.188	8	67.141	67.123	40	63.301	63.295	13	56.31	
$^3P_0$	$^3P_1$	6	70.606	70.657	2	66.36	66.408	2	62.354	62.440			
$^1S_0$	$^1P_1$	3	80.844	80.887	3	78.29	78.333						
$^3P_1$	$^3P_1$	8	78.757	78.749	3	75.40	75.392	20	72.27	72.288			
$^3P_1$	$^3P_2$	2	89.055	89.053	5	85.83	85.806	11	82.79	82.765			
$2s2p^5\,^1P_1$–$2p^6$	$^1S_0$	0	81.048	81.083	5	77.55[b]	77.610	12	74.350	74.402			

[a] The predicted wavelengths are from Edlén (Ref. 3).
[b] Blend.

Table 2. Energy Levels Isoelectronic with F I (in inverse centimeters)

Level	As XXV	Se XXVI	Br XXVII	Rb XXIX
$2s^22p^5\,^2P_{3/2}$	0	0	0	0
$^2P_{1/2}$	302630	346070	393650	504370
$2s2p^6\,^2S_{1/2}$	1606430	1699870	1798140	2010940

Table 3. Energy Levels Isoelectronic with O I (in inverse centimeters)

Level	As XXVI	Se XXVII	Br XXVIII	Rb XXX
$2s^22p^4\,^3P_2$	0	0	0	0
$^3P_0$	135470	144020	151560	
$^3P_1$	281860	324500	371740	481500 + y
$^1D_2$	376130	420920 + x	470830	584100 + x
$^1S_0$	725800	813930 + x		
$2s2p^5\,^3P_2$	1404670	1489500	1579620	1775900
$^3P_1$	1551780	1650960	1755310	1979400
$^3P_0$	1717430	1846870	1986440	2295000 + y
$^1P_1$	1962750	2091230 + x	2230150	2537200 + x
$2p^6\,^1S_0$	3196580	3380720 + x	3575140	

Table 4. Predicted Wavelengths of Magnetic-Dipole Transitions (in angstroms)

Transition	As	Se	Br	Rb
$2s^22p^5$				
$^2P_{3/2}$–$^2P_{1/2}$	330.44	288.96	254.03	198.27
$2s^22p^4$				
$^3P_1$–$^1S_0$	225.26	204.32		
$^3P_2$–$^1D_2$	265.87	237.57	212.39	171.2
$^3P_2$–$^3P_1$	354.79	308.17	269.01	207.7
$^3P_0$–$^3P_1$	683.11	554.08	454.17	
$^3P_1$–$^1D_2$	1060.78	1037.13	1009.18	974.7

to three digits is estimated to be 0.005 Å unless there occurs some systematic shift with respect to the standards. For the wavelengths given to only two digits, the accuracy is about 0.01 Å.

The measured wavelengths (λ_{meas}) and the relative intensities of the spectral lines are listed in Table 1. The measured wavelengths have been compared with Edlén's[3] predicted wavelengths (λ_{pred} in Table 1). The predicted wavelengths for the F I transitions are higher than our measured wavelengths by 0.001 to 0.016 Å. The largest discrepancy occurs for the $^2P_{1/2}$–$^2S_{1/2}$ transitions in Br and Rb (0.015 and 0.016 Å, respectively). The predicted wavelengths for these two elements are based primarily on interpolation from the measurements of Reader[2] for Sr and Y with a quoted accuracy of 0.015 Å. We conclude that Edlén's predicted wavelengths are systematically larger than our measured wavelengths, but the differences are within the uncertainties in the currently measured wavelengths and in the predicted wavelengths.

In the case of the O I transitions, the predicted wavelengths listed in Table 1 represent extrapolations from elements with atomic numbers $Z = 32$ and below. For most of the transitions listed in Table 1, the measured and predicted wavelengths agree to within 0.02 Å. Discrepancies of 0.030 to 0.086 Å occur for the $^3P_0$–$^3P_1$, $^1S_0$–$^1P_1$, and $^1P_1$–$^1S_0$ transitions, and these discrepancies are much greater than the uncertainties in the measured wavelengths.

The energy levels that are derived from the measured wavelengths are listed in Tables 2 and 3. The uncertainty in the energy levels is estimated to be 200 cm^{-1}. For Se XXVII and Rb XXX, the number of observed transitions was insufficient to determine all the energy levels, and we adopted Edlén's[3] energy levels with the uncertainties indicated in Table 3 as $+x$ and $+y$.

Listed in Table 4 are the predicted wavelengths, based on the energy levels of Tables 3 and 4, for a number of magnetic-dipole transitions within the ground configurations of the F I and O I isoelectronic sequences. Our predicted wavelength of 198.27 Å for the $^2P_{3/2}$–$^2P_{1/2}$ transition in Rb XXIX agrees with the prediction of 198.21 of Reader.[2]

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