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LIFETIMES, BRANCHING RATIOS, AND TRANSITION PROBABILITIES IN Mo I

W. WHALING†
Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, CA 91125, U.S.A.

P. HANNAFORD and R. M. LOWE
CSIRO Division of Chemical Physics, P.O. Box 160, Clayton, Victoria 3168, Australia

and

E. BIÉMONT‡ and N. GREVESSE
Institut d'Astrophysique, Université de Liège, B-4200 Cointe-Liège, Belgium

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Abstract—The radiative lifetimes of 56 levels in Mo I have been measured by the method of laser-induced fluorescence from sputtered metal vapor. Emission branching ratios have been measured for these levels to determine transition probabilities for 570 Mo I transitions in the wavelength range 2944–9767 Å. The uncertainty in the transition probability of stronger branches is typically less than 5%.

1. INTRODUCTION

We have recently measured the transition probability for twelve Mo I lines seen in the solar spectrum in order to find the solar Mo abundance.[1] Our experimental method determines the transition probability for many additional Mo lines that were not used for our solar abundance study but which may be useful for the analysis of other stars or terrestrial plasmas. In this paper we describe the measurement of the transition probabilities and present all of the radiative lifetimes, emission branching ratios, and transition probabilities that we have measured. Finally we compare our values with earlier measurements where possible.

2. LIFETIME MEASUREMENTS

Radiative lifetimes in neutral molybdenum have been determined using the technique of laser-induced fluorescence from sputtered metal vapor,[2,3] a technique that is suitable for lifetime measurements in neutral and singly-ionized atoms of the refractory metals. With this method, an atomic vapor of molybdenum is produced by cathodic sputtering in a low-pressure rare-gas discharge and the atoms excited selectively to the required level by short optical pulses (3–4 ns duration, 0.1 Å bandwidth) from a nitrogen-laser pumped dye laser. Fluorescence decay signals from the excited atoms are detected by a photomultiplier wired for fast response and recorded and integrated in a 500 MHz transient digitiser. When necessary, the dye laser output is frequency-doubled with KDP crystals. The laser radiation is polarised at an angle of 54.7° with respect to the direction of detection in order to eliminate any effects of collisional disalignment by the rare gas, and stray magnetic fields in the region of observation are compensated by Helmholtz coils. The method is essentially free of cascading, line blending, and transit-time effects. For all levels studied, checks are made for the presence of radiation trapping and collisional depopulation by making measurements at different Mo atomic densities and rare-gas pressures.

Lifetime measurements have been made for 56 levels of Mo I. Many of these levels were excited from metastable levels (a^5S, a^5D, a^5G, a^5P, b^5D) whose energies are in the range 11000–21000 K. For 15 of the levels, a small degree of collisional depopulation was

†Guest observer, Kitt Peak National Observatory, operated by AURA under contract with the *NSF*.
‡Research Associate of the Belgian National Fund for Scientific Research (F.N.R.S.)

observed and these lifetimes were determined by extrapolation to zero pressure of rare gas. For one level ($z^3H_6^0$) this correction amounted to approx. 5% of the lifetime measured at the lowest pressure, and for the remaining 14 levels the correction was less than 2%. No radiation trapping effects were detected in these measurements.

Lifetime measurements have previously been reported for a total of 15 levels in Mo I and a comparison of our results with earlier work is shown in Table 1. The full list of the 56 lifetimes measured in this work is given in Table 2. The results shown in Table 1, which include four independent sets of measurements using laser-induced fluorescence techniques, are a good example of the high level of agreement commonly attained in recent lifetime measurements of refractory metal atoms. In particular the agreement with the results of Kwiatkowski *et al.*[4,5] is better than 2% for all levels except the long-lived $z^7D_4^0$ level, for which there is a difference of about 25%. The reason for this one discrepancy is not clear, although differences of this magnitude could arise if fluorescence decay curves were distorted by Zeeman beats induced by stray magnetic fields.

3. EMISSION BRANCHING RATIOS

The emission branching ratio R_{ul} for the transition from upper level u to lower level l is defined

$$R_{ul'} = A_{ul'}/\sum_l A_{ul} = I_{ul'}/\sum_l I_{ul} \quad (1)$$

where I_{ul} is the photon intensity (photons/sec) of the line λ_{ul} with transition probability A_{ul}.

Table 1. Radiative lifetimes of those Mo I levels that have been measured by other observers. For a complete list of all level lifetimes measured in this experiment, see Table 2. The uncertainty in the measured lifetime appears in parentheses.

LEVEL	ENERGY (K)	LIFETIME (ns)				
		Laser-induced Fluorescence				Hanle
		This work	Kwiatkowski et al[4,5]	Duquette et al[11]	Rudolph & Helbig[12]	Baumann et al[13]
z7Po2	25614	16.0(5)	16.3(8)a	17.1(9)	15.9(8)	13.6(7)
z7Po3	25872	15.6(5)	15.8(8)a	17.0(9)	16.9(8)	15.8(8)
z7Po4	26320	14.5(5)	14.7(7)a	15.9(8)	15.6(8)	14.4(8)
z5Po1	28715	20.3(5)	20.6(1.0)b	21.7(1.1)		
z5Po2	28837	19.8(5)	20.3(1.0)b	22.1(1.1)		
z5Po3	28294	20.0(5)	20.5(1.0)b	22.3(1.1)		
z7Do2	31157	35.4(1.0)	35.6(2.0)a			8.2(8)
z7Do3	31658	21.5(5)	21.2(1.0)a		21.8(1.5)	22.1(1.0)
z7Do4	32123	155(5)	119(8)a			
y7Po2	31300	6.5(3)	6.6(3)a			6.0(5)
y7Po3	31533	7.3(3)	7.3(4)a		7.5(5)	10.2(5)
y7Po4	31933	5.6(3)	5.6(3)a		5.8(4)	5.7(6)
y5Fo1	41012	9.0(1)	9.0(5)b			
y5Fo2	41032	7.1(3)	7.2(4)b			

a. Ref 4.

b. Ref 5.

Table 2. Lifetimes, branching ratios, and transition probabilities in Mo I. The uncertainty in a value appears in parentheses immediately following the value. Transition probabilities measured by others appear in the last two columns. Wavelengths in the third column are computed from the energy levels in Ref 8.

UPPER LEVEL Energy Lifetime	LOWER LEVEL	λ (Å)	BRANCHING RATIO (%)	TRANSITION PROBABILITY (10^6 s^{-1}) This work	(a)	(b)
z7Po 2	a7S 3	3902.96	98.6(2)	62(2)	65	42
25614 K	a5S 2	6733.97	0.97(5)	0.60(9)		0.32
16.0(5) ns	a5D 1	6908.24	0.05(1)	0.033(5)		0.040
	a5D 2	7060.26	0.13(2)	0.08(1)		0.082
	a5D 3	7267.67	0.24(4)	0.15(2)		0.086
z7Po 3	a7S 3	3864.11	97.3(5)	62(2)	65	49
25872 K	a5S 2	6619.14	1.9(4)	1.2(3)		
15.6(5) ns	a5D 2	6934.13	0.07(1)	0.05(1)		
	a5D 3	7134.10	0.22(4)	0.14(3)		
	a5D 4	7391.38	0.52(1)	0.33(7)		
z7Po 4	a7S 3	3798.26	100	69(2)	68	49
26320 K						
14.5(5) ns						
z5Po 1	a5S 2	5570.43	65.6(2)	32.3(8)	28	20
28715 K	a5D 0	5632.46	7.16(5)	3.53(9)		2.6
20.3(5) ns	a5D 1	5689.14	14.5(1)	7.1(2)		3.7
	a5D 2	5791.85	12.6(1)	6.2(2)		4.3
	a5P 2	9651.02	0.15(1)	0.074(9)		
	a5P 1	9767.11	0.071(8)	0.035(4)		
z5Po 2	a7S 3	3466.82	2.4(1)	1.23(6)		
28837 K	a5S 2	5533.03	71.0(4)	35.9(9)	34	26
19.8(5) ns	a5D 1	5650.14	3.14(4)	1.58(5)		1.2
	a5D 2	5751.42	8.5(1)	4.3(1)		3.2
	a5D 3	5888.32	14.6(2)	7.3(2)		4.2
	a5P 3	9424.82	0.17(5)	0.09(3)		
	a5P 1	9652.71	0.18(6)	0.09(3)		
z5Po 3	a7S 3	3456.39	4.2(2)	2.1(1)		4.4
28924 K	a5S 2	5506.50	68.5(2)	34.2(9)	35	29
20.0(5) ns	a5D 2	5722.76	1.94(7)	0.97(3)		0.80
	a5D 3	5858.28	5.93(3)	3.0(1)		2.0
	a5D 4	6030.66	18.8(1)	9.4(3)		5.1
	a5P 3	9348.10	0.33(9)	0.17(5)		
	a5P 2	9460.71	0.28(9)	0.14(4)		
z7Do 1	a5S 2	4979.12	90(3)	2.3(3)		2.8
30847 K	a5D 0	5028.62	0.16(6)	0.004(2)		
390(50) ns	a5D 1	5073.75	0.23(8)	0.006(2)		
	a5D 2	5155.28	1.5(4)	0.04(1)		
	b5D 0	9191.39	1.2(4)	0.03(1)		
	b5D 1	9329.08	3.8(1.1)	0.10(3)		
	b5D 2	9462.10	3.4(1.0)	0.09(3)		
z7Do 2	a7S 3	3208.83	96.7(7)	27.3(8)	30	34
31155 K	a5S 2	4903.79	2.5(5)	0.7(1)		0.68
35.4(1.) ns	a5D 2	5074.57	0.23(5)	0.07(1)		
	a5D 3	5180.84	0.021(5)	0.006(2)		
	a5P 2	7811.26	0.10(2)	0.029(7)		
	a5P 1	7887.13	0.07(2)	0.019(5)		
	b5D 1	9068.09	0.23(8)	0.06(2)		
	b5D 2	9193.72	0.13(4)	0.04(1)		
	b5D 3	9252.86	0.3(1)	0.08(3)		
y7Po 2	a7S 3	3193.97	99.4(3)	153.(8)	147	88
31300 K	a5S 2	4869.18	0.5(2)	0.8(3)		0.56
6.5(3) ns	a5D 1	4959.64	0.02(1)	0.03(1)		
	a5D 2	5037.51	0.02(1)	0.03(1)		
	a5D 3	5142.23	0.05(2)	0.07(3)		
y7Po 3	a7S 3	3170.34	99.6(2)	136(5)	122	77
31533 K	a5D 3	5081.25	0.20(7)	0.28(7)		0.23
7.3(3) ns	a5D 4	5210.42	0.16(2)	0.22(7)		0.19
z7Do 3	a7S 3	3158.16	99.3(1)	46(1)	45	54
31655 K	a5S 2	4786.45	0.6(1)	0.28(5)		0.33
21.5(5) ns	a5D 2	4949.02	0.12(2)	0.06(1)		
	a5D 4	5177.63	0.009(2)	0.004(1)		
y7Po 4	a7S 3	3132.59	100.	178(10)	165	109
31913 K						
5.6(3) ns						
z7Do 4	a7S 3	3112.12	97.8(.3)	6.3(2)	6.5	11
32123 K	a5D 3	4933.33	1.6(1)	0.11(1)		
155(5) ns	a5D 4	5055.01	0.45(6)	0.029(4)		0.31
	a5P 3	7195.40	0.19(4)	0.012(2)		
y5Po 1	a5S 2	4517.39	12.1(1)	0.69(4)		1.7
32899 K	a5D 0	4558.10	20.0(2)	1.14(7)		3.3
175(10) ns	a5D 1	4594.32	33.3(3)	1.9(1)		4.7
	a5D 2	4661.92	16.4(2)	0.93(6)		2.1
	a5P 2	6874.60	0.39(3)	0.022(2)		
	a5P 1	6933.30	0.31(8)	0.018(4)		
	b5D 0	7732.45	3.4(1)	0.19(1)		0.47
	b5D 1	7829.66	7.5(3)	0.43(3)		0.97
	b5D 2	7923.15	6.6(3)	0.38(2)		0.60

Table 2 (*Contd*)

UPPER LEVEL Energy Lifetime	LOWER LEVEL	λ (Å)	BRANCHING RATIO (%)	TRANSITION PROBABILITY (10^6 s^{-1}) This work (a)	(b)
y5Po 2	a7S 3	3002.21	8.8(4)	0.65(4)	3.8
33299 K	a5S 2	4437.13	1.65(3)	0.121(5)	
136(5) ns	a5D 1	4512.13	13.6(2)	1.00(4)	3.0
	a5D 2	4576.49	29.1(3)	2.14(8)	4.8
	a5D 3	4662.75	27.9(1)	2.06(8)	4.0
	a5P 2	6690.45	2.89(7)	0.212(9)	0.48
	a5P 1	6746.03	4.13(8)	0.30(1)	0.56
	b5D 1	7591.67	0.80(4)	0.059(3)	0.24
	b5D 2	7679.52	3.3(1)	0.24(1)	0.48
	b5D 3	7720.75	7.9(2)	0.58(3)	1.0
y5Po 3	a7S 3	2944.21	7.5(4)	0.64(5)	2.3
33955 K	a5S 2	4311.59	0.30(2)	0.026(2)	
117(5) ns	a5D 2	4443.07	8.1(1)	0.69(3)	2.0
	a5D 3	4524.33	20.5(2)	1.76(8)	4.4
	a5D 4	4626.45	46.8(1)	4.0(2)	7.3
	a5P 3	6357.20	5.5(1)	0.47(2)	0.70
	a5P 2	6409.08c	3.01(5)	0.26(1)	0.46
	b5D 2	7311.10	0.15(2)	0.013(1)	
	b5D 3	7348.46	0.93(3)	0.080(4)	0.39
	b5D 4	7245.86	7.1(2)	0.61(4)	1.1
z5Fo 1	a5D 0	4293.87	45.3(3)	5.9(2)	16
34248 K	a5D 1	4326.74	34.3(2)	4.5(2)	12
77(3) ns	a5D 2	4385.89	2.04(2)	0.27(1)	1.2
	a5G 2	5677.87	10.7(2)	1.39(6)	1.6
	b5D 0	7001.57	4.0(1)	0.52(2)	0.93
	b5D 1	7081.18	3.0(1)	0.39(2)	0.97
	b5D 2	7157.56	0.30(3)	0.039(4)	
	a3P 0	7328.90	0.33(4)	0.043(5)	
z5Fo 2	a5D 1	4292.13	56.0(5)	7.0(3)	20
34435 K	a5D 2	4350.33	24.5(3)	3.1(1)	6.8
80(3) ns	a5D 3	4428.21	0.5(1)	0.06(1)	
	a5G 2	5618.76	2.2(2)	0.28(3)	0.48
	a5G 3	5634.86	7.1(3)	0.88(5)	1.2
	a5P 3	6217.89	1.9(1)	0.24(2)	0.52
	a5P 3	6265.87	1.4(2)	0.18(3)	0.44
	b5D 1	8988.96	4.6(2)	0.58(3)	0.98
	b5D 2	7063.35	1.8(4)	0.22(5)	0.60
z5Fo 3	a5S 2	4170.35	0.35(1)	0.045(2)	
34740 K	a5D 2	4293.22	64.7(2)	8.3(3)	20
78(3) ns	a5D 3	4369.05	14.9(4)	1.9(1)	5.3
	a5G 3	5539.41	2.30(3)	0.29(1)	0.40
	a5G 4	5556.28	6.1(1)	0.78(3)	0.84
	a5P 3	6054.83	1.39(4)	0.178(8)	
	a5P 2	6101.88	3.48(6)	0.44(2)	0.84
	b5D 2	6914.02	5.1(1)	0.65(3)	
	b5D 3	6947.42	1.45(5)	0.187(9)	0.30
	a3D 2	7249.89	0.24(2)	0.031(3)	
z5Fo 4	a5D 3	4288.63	75.(2)	10.5(5)	27
35169 K	a5D 4	4380.29	6.2(4)	0.86(6)	3
72(3) ns	a5G 4	5426.87	1.6(1)	0.22(2)	0.37
	a5G 5	5437.75	4.9(4)	0.68(6)	1.06
	a5P 3	5901.48	4.3(3)	0.60(5)	0.71
	b5D 3	6746.28	6.7(5)	0.92(8)	0.31
	b5D 4	6659.70	0.95(8)	0.13(1)	0.32
	a3G 3	7029.63	0.08(2)	0.011(2)	
z5Fo 5	a5D 4	4277.23	86(1)	13(1)	22
35719 K	a5G 5	5279.82	0.78(6)	0.12(1)	d
64(6) ns	a5G 6	5279.64	3.2(3)	0.50(6)	1.0d
	b5D 4	6424.35	9.9(9)	1.5(2)	1.8
	a3F 4	8192.56	0.17(2)	0.027(5)	0.16
z5Do 0	a5D 1	3847.24	80.6(5)	23(1)	100
37128 K	a5P 1	5360.87	11.8(2)	3.4(2)	
34.5(2.) ns	b5D 1	5881.50	4.9(1)	1.4(1)	2.7
	a5F 1	9218.89	2.7(4)	0.78(14)	
z5Do 1	a5D 0	3797.30	20.6(1)	5.9(2)	28
37293 K	a5D 1	3822.98	11.5(1)	3.3(1)	18
35(1) ns	a5D 2	3869.09	51.0(2)	14.6(4)	57
	a5P 2	5279.35	1.20(4)	0.34(1)	
	a5P 1	5313.90	8.0(1)	2.28(7)	5.0
	b5D 0	5771.02	1.15(4)	0.33(1)	0.90
	b5D 1	5825.00	1.36(4)	0.38(2)	2.2
	b5D 2	5876.59	4.4(1)	1.26(5)	2.5
	c5D 1	8714.23	0.82(8)	0.23(2)	
y5Do 0	a5D 1	3812.38	12.0(4)	1.8(1)	
37366 K	a5P 1	5293.44	43.8(2)	6.6(4)	8.6
66(4) ns	b5D 1	5800.43	40.3(2)	6.1(4)	7.5
	a3P 1	6611.38	3.9(3)	0.59(5)	

Table 2 (*Contd*)

UPPER LEVEL Energy Lifetime	LOWER LEVEL	λ (Å)	BRANCHING RATIO (%)	TRANSITION PROBABILITY (10^6 s^{-1}) This work (a)	(b)
z5Do 2	a5S 2	3728.77	0.34(1)	0.095(5)	
37579 K	a5D 1	3781.59	17.1(1)	4.7(1)	26
36(1) ns	a5D 2	3826.69	28.7(1)	8.0(2)	32
	a5D 3	3886.82	35.0(1)	9.7(3)	36
	a5P 3	5166.52	0.09(2)	0.026(4)	
	a5P 2	5200.74	3.7(1)	1.04(3)	2.6
	a5P 1	5234.26	5.3(1)	1.48(5)	5.4
	b5D 1	5729.45	0.84(2)	0.234(5)	1.6
	b5D 2	5779.35	3.2(1)	0.88(3)	2.4
	b5D 3	5802.66	3.5(1)	0.98(3)	2.0
	a3D 1	6004.78	0.14(1)	0.040(3)	
	a3D 2	6012.16	0.18(2)	0.049(5)	
	a3F 3	6186.52	0.14(2)	0.038(6)	
	c5D 2	8483.33	0.9(1)	0.25(3)	
	a5F 3	8777.41	0.74(7)	0.20(2)	
y5Do 1	a5S 2	3684.47	1.59(5)	0.19(1)	
37902 K	a5D 0	3711.51	6.4(1)	0.76(4)	3.3
84(4) ns	a5D 1	3736.04	2.43(5)	0.29(2)	
	a5D 2	3780.06	0.51(4)	0.061(6)	
	a5P 2	5114.97	24.6(1)	2.9(1)	8
	a5P 1	5147.39	28.6(1)	3.4(2)	11
	b5D 0	5575.17	17.1(2)	2.0(1)	3.3
	b5D 1	5625.53	0.73(4)	0.87(7)	
	b5D 2	5673.63	14.1(1)	1.68(8)	2.5
	a3P 0	5780.76	0.34(3)	0.040(4)	
	a3P 2	6653.50	0.46(5)	0.054(6)	
	a3D 1	5890.74	1.29(3)	0.154(8)	
	a3D 2	5897.84	1.78(5)	0.21(1)	
z5Do 3	a5S 2	3675.41	1.12(3)	0.31(1)	
37968 K	a5D 2	3770.51	11.4(2)	3.1(1)	
36(1) ns	a5D 3	3828.87	52.3(2)	14.5(4)	47
	a5D 4	3901.77	19.1(2)	5.3(2)	19
	a5P 3	5064.64	1.25(3)	0.35(1)	1.2
	a5P 2	5097.51	9.8(1)	2.7(1)	5.6
	b5D 2	5652.16	0.48(2)	0.134(7)	
	b5D 3	5674.46	0.64(3)	1.78(6)	2.7
	b5D 4	5613.09	2.57(5)	0.71(3)	1.1
	a3F 4	6917.57	0.24(2)	0.066(6)	
	a3F 3	6990.91	0.18(4)	0.05(1)	
	c5D 3	8153.49	1.04(8)	0.29(3)	0.90
z5Do 4	a5D 3	3763.35	5.24(4)	1.33(4)	7.3
38423 K	a5D 4	3833.74	64.9(4)	16.4(4)	74.
39.5(1.)ns	a5G 4	4612.24	0.06(1)	0.015(1)	
	a5P 3	4950.62e	12.4(2)	3.1(1)	4.2
	b5D 3	5531.71	0.38(4)	0.10(1)	
	b5D 4	5473.37	13.1(2)	3.3(1)	0.53
	a3D 3	5949.14	0.22(3)	0.055(8)	
	a3G 4	5789.03	0.15(1)	0.038(3)	
	c5D 4	7709.45	0.90(7)	0.23(2)	0.74
	c5D 3	7861.98	0.44(4)	0.11(1)	
	a5F 5	7986.61	2.2(2)	0.56(5)	1.3
y5Do 2	a5D 1	3651.34	11.7(2)	2.16(9)	14
38522 K	a5D 2	3693.37	10.1(1)	1.86(8)	15
54(2) ns	a5D 3	3749.35	1.56(3)	0.29(1)	
	a5G 3	4579.72	0.93(4)	0.17(1)	
	a5P 3	4926.43	5.69(5)	1.05(4)	2.8
	a5P 2	4957.52	34.8(2)	6.5(3)	10
	a5P 1	4987.98	2.09(4)	0.39(2)	
	b5D 1	5435.67	10.6(1)	2.00(8)	4.2
	b5D 2	5480.56	0.52(2)	0.097(7)	
	b5D 3	5501.53	10.0(1)	1.87(7)	3.6
	a3P 1	6141.62	0.27(7)	0.05(1)	
	a3D 1	5682.89	6.0(1)	1.11(5)	2.6
	a3D 2	5689.49	4.9(1)	0.90(4)	
	a3D 3	5914.24	0.75(3)	0.14(1)	
z5Go 2	a5G 2	4474.56	72.4(5)	21.1(6)	68
38983 K	a5G 3	4484.97	17.9(1)	5.2(2)	16
34.4(1.)ns	a5P 3	4816.96	0.49(1)	0.144(5)	
	a5P 2	4846.69	0.19(2)	0.054(4)	
	b5D 2	5345.43	0.14(2)	0.014(5)	
	a3P 2	6206.62	0.21(7)	0.060(2)	
	a3D 1	5537.72	0.40(3)	0.12(1)	
	a3D 2	5544.00	0.65(3)	0.19(1)	
	a3G 3	5543.07	5.9(1)	1.74(6)	4.2
	a3F 2	6471.15	1.7(7)	0.5(2)	(2.0)[f]

Table 2 (*Contd*)

UPPER LEVEL Energy Lifetime	LOWER LEVEL	λ (Å)	BRANCHING RATIO (%)	TRANSITION PROBABILITY (10^6 s^{-1}) This work	(a)	(b)
z5Go 3	a5S 2	3525.94	2.70(5)	0.81(3)		
39121 K	a5D 2	3613.38	5.62(7)	1.68(5)		12
33.5(1.)ns	a5D 3	3666.94	5.75(6)	1.72(5)		8.3
	a5D 4	3733.74	0.38(3)	0.11(1)		
	a5G 3	4457.36	43.0(2)	12.8(4)		39
	a5G 4	4468.27	17.2(1)	5.1(2)		16
	a5P 3	4785.13	10.3(1)	3.1(1)		6.3
	a5P 2	4814.46g	1.49(2)	0.44(2)		
	b5D 2	5306.25	1.45(3)	0.43(2)		1.2
	b5D 3	5325.90	0.60(2)	0.180(8)		
	b5D 4	5271.80	2.13(3)	0.64(2)		2.0
	a3D 2	5501.87	3.08(4)	0.92(3)		1.4
	a3D 3	5711.76	1.84(3)	0.55(2)		1.6
	a3G 4	5564.02	1.75(2)	0.52(2)		1.3
	a3F 4	6406.45	0.54(2)	0.160(7)		
	a3F 3	6469.30	0.10(2)	0.03(1)		
	a3H 4	6653.64	0.20(5)	0.06(2)		
	c5D 4	7315.47	0.20(3)	0.06(1)		
	c5D 2	7501.59	0.70(8)	0.21(2)		0.71
	a5F 4	7617.44	0.46(9)	0.14(3)		
	a5F 3	7730.63	0.5(1)	0.15(4)		
y5Do 3	a5S 2	3521.17	4.66(5)	1.41(5)		
39160 K	a5D 2	3608.37	11.0(1)	3.3(1)		19
33(1) ns	a5D 3	3661.78	8.17(7)	2.47(8)		16
	a5D 4	3728.39	0.62(3)	0.19(1)		
	a5G 3	4449.74	28.1(1)	8.5(3)		27
	a5G 4	4460.61	2.44(1)	0.74(3)		5.1
	a5P 3	4776.35	21.0(1)	6.3(2)		11
	a5P 2	4805.57	2.60(2)	0.79(3)		
	b5D 2	5295.46	3.64(3)	1.10(3)		3.6
	b5D 3	5315.03	2.22(2)	0.67(2)		2.0
	b5D 4	5261.14	6.77(6)	2.05(6)		4.0
	a3P 2	6139.35	0.3(1)	0.09(2)		
	a3D 2	5490.26	3.10(3)	0.94(3)		2.1
	a3D 3	5699.25	2.57(3)	0.78(3)		1.6
	a3G 3	5489.35	0.3(1)	0.10(3)		
	a3G 4	5552.15	0.71(2)	0.21(1)		0.64
	a3F 4	6390.72	0.17(4)	0.05(1)		
	a3F 3	6453.26	0.51(2)	0.155(8)		
	a5F 4	7295.21	0.71(4)	0.22(1)		
	a5F 3	7707.74	0.44(3)	0.132(9)		
z5Go 4	a5G 3	4424.19	0.57(3)	0.17(1)		
39290 K	a5G 4	4434.94	82.7(1)	25.3(8)		66
32.7(1.)ns	a5G 5	4442.20	16.1(1)	4.9(2)		13
	a3G 3	5450.52	0.44(2)	0.135(8)		
	a3H 4	6580.00	0.19(2)	0.06(1)		
z5Go 5	a5D 4	3689.14	0.07(1)	0.021(3)		
39445 K	a5G 4	4404.54	1.00(2)	0.30(1)		1.7
33.2(1.)ns	a5G 5	4411.70	87.1(1)	26.2(8)		136d
	a5G 6	4411.58	9.7(1)	2.91(9)		d
	a3G 4	5465.54	1.12(2)	0.34(1)		
	a3H 5	6673.94	0.14(2)	0.043(4)		
	a5F 4	7434.06	0.91(5)	0.27(2)		0.88
x5Po 2	a5S 2	3484.00	0.49(3)	0.105(7)		
39463 K	a5D 3	3621.60	1.30(4)	0.27(1)		
47(2) ns	a5G 2	4380.57	4.75(2)	1.01(4)		4.4
	a5P 3	4708.22	38.0(1)	8.1(3)		17
	a5P 2	4736.62	1.89(4)	0.40(2)		
	a5P 1	4764.41	13.0(1)	2.8(1)		8.4
	b5D 1	5171.23	8.3(1)	1.77(8)		
	b5D 2	5211.85	6.0(2)	1.27(6)		4.6
	a3P 1	5806.16	1.90(4)	0.40(2)		1.0
	a3P 2	6027.25	4.00(4)	0.85(4)		1.8
	a3D 1	5394.49	11.3(1)	2.4(1)		
	a3D 2	5400.44	8.4(1)	1.80(7)		
	a3D 3	5602.53	0.57(5)	0.12(1)		
z5Go 6 m	a5G 5	4396.77	3.3(1)	0.50(5)		d
39522 K	a5G 6	4396.65	71.5(6)	10.8(8)		6.5d
66(5) ns	a3H 5	6639.82	25.2(6)	3.8(3)		
z5Ho 7	a5G 6	4381.64	99.7(1)	31(1)		80
39600 K	a3H 6	6765.60	0.29(2)	0.091(6)		
32(1) ns						
z5Ho 3	a5S 2	3449.48	0.39(3)	0.109(7)		
39750 K	a5G 2	4326.13	92.8(4)	25.8(7)		79
36(1) ns	a5G 4	4346.19	1.57(2)	0.44(2)		
	a5P 3	4645.39	0.39(2)	0.109(6)		
	a5P 2	4673.03	0.45(3)	0.123(7)		
	b5D 2	5134.97	0.84(3)	0.23(1)		
	b5D 3	5153.37	0.36(3)	0.100(8)		
	a3D 2	5317.94	1.17(3)	0.33(1)		
	a3D 3	5513.78	0.42(2)	0.117(7)		
	a3G 3	5317.08	0.60(2)	0.17(1)		
	a3G 4	5379.98	0.29(2)	0.080(6)		
	a3F 4	6158.43	0.8(4)	0.2(1)		

Table 2 (*Contd*)

UPPER LEVEL Energy Lifetime	LOWER LEVEL	λ (Å)	BRANCHING RATIO (%)	TRANSITION PROBABILITY (10^6 s^{-1}) This work	(a)	(b)
y5Do 4	a5D 3	3563.14	26.5(3)	8.3(3)		33
39916 K	a5G 3	4304.92	2.11(2)	0.66(2)		3.2
32(1) ns	a5G 4	4315.10	0.73(2)	0.23(1)		
	a5G 5	4321.98	3.31(3)	1.04(3)		5.6
	a5P 3	4609.89	31.0(2)	9.7(3)		23
	b5D 3	5109.72	10.6(1)	3.3(1)		7.6
	b5D 4	5059.90	25.2(2)	7.9(3)		11
	a3D 3	5463.85	0.20(2)	0.063(5)		
	a3G 4	5328.50	0.13(1)	0.041(4)		
	a3F 4	6096.20	0.27(2)	0.083(6)		
x5Po 3	a5S 2	3424.59	21.2(3)	5.9(3)		21
39961 K	a5D 2	3507.02	1.90(3)	0.53(3)		
36(2) ns	a5D 3	3557.45	1.16(3)	0.32(2)		
	a5G 2	4287.06	7.89(8)	2.2(1)		11
	a5G 3	4296.62	2.57(5)	0.71(4)		3.1
	a5P 2	4627.47	7.22(7)	2.0(1)		8.8
	b5D 2	5080.01	14.1(2)	3.9(2)		7.3
	b5D 3	5098.02	4.41(5)	1.23(7)		2.4
	a3P 2	5851.63	0.90(3)	0.25(2)		
	a3D 2	5259.02	20.1(2)	5.6(3)		11.4
	a3D 3	5450.47	7.7(1)	2.1(1)		3.3
	a3G 3	5258.18	0.20(2)	0.057(6)		
	a3G 4	5315.78	1.03(3)	0.028(2)		2.0
	a3F 4	6079.56	3.10(5)	0.86(5)		1.7
	c5D 4	6892.29	2.86(7)	0.79(5)		2.0
	c5D 3	7013.94	0.54(3)	0.15(1)		
	a5F 4	7159.70	0.64(4)	0.18(1)		
	b3D 2	7572.62	2.4(1)	0.68(4)		1.9
z5Ho 4	a5D 4	3606.30	0.40(2)	0.121(7)		
40068 K	a5G 3	4276.92	93.8(1)	28(1)		70
33(1) ns	a5G 4	4286.97	0.87(3)	0.26(1)		
	a5G 5	4293.76	1.93(4)	0.58(2)		
	a5P 3	4577.80	1.27(3)	0.38(2)		
	b5D 4	5021.26	0.55(3)	0.17(1)		
	a3D 3	5418.82	0.10(1)	0.031(3)		
	a3G 3	5228.72	0.28(2)	0.085(6)		
	a3G 4	5285.67	0.29(2)	0.087(7)		
	a3G 5	5339.11	0.32(1)	0.96(5)		
	a3H 5	6407.68	0.20(1)	0.61(4)		
z5Ho 5	a5D 4	3567.73	0.41(2)	0.13(1)		
40367 K	a5G 4	4232.58	95.4(1)	31(1)	48	100
30.5(1.) ns	a5G 5	4239.20	1.33(1)	0.44(2)		d
	a5G 6	4239.08	2.03(2)	0.67(2)		6.5d
	a3G 4	5203.26	0.30(2)	0.099(6)		
	c5D 4	6704.27	0.08(2)	0.027(7)		
	a3F 4	6957.01	0.47(4)	0.15(2)		
x5Do 3	a5S 2	3363.77	41(1)	28.(2)	23	113
40488 K	a5D 2	3443.26	12.5(2)	8.4(6)		31
15.0(1.) ns	a5D 3	3491.86	1.46(3)	0.97(7)		
	a5D 4	3552.39	0.76(3)	0.51(4)		
	a5G 2	4192.17	0.14(1)	0.09(1)		
	a5G 3	4201.31	1.29(4)	0.86(7)		
	a5G 4	4211.00	1.23(4)	0.82(6)		
	a5P 3	4491.28	11.9(3)	7.9(6)		27
	a5P 2	4517.11	12.0(3)	8.0(6)		27
	b5D 2	4947.32	0.16(1)	0.11(1)		
	b5D 3	4964.40	3.2(1)	2.1(2)		3.4
	b5D 4	4917.36	0.25(2)	0.17(2)		
	a3D 2	5116.94	0.95(4)	0.63(5)		
	a3D 3	5298.01	0.71(3)	0.48(4)		
	a3G 4	5170.66	0.42(3)	0.28(3)		
	a3F 3	5943.58	0.25(2)	0.17(2)		
	c5D 4	6650.30	8.6(4)	5.7(5)		7.4
	c5D 3	6763.48	0.80(5)	0.53(5)		
	a5F 4	6898.92	0.78(4)	0.52(4)		
	a5F 3	6991.63	1.10(6)	0.74(6)		
	a5F 2	7063.95	0.27(3)	0.18(2)		
x5Do 1	a5S 2	3340.15	13.2(1)	12.3(6)	10	70
40698 K	a5D 0	3362.36	10.19(9)	9.5(5)	13	37
10.7(5) ns	a5D 1	3382.48	31.5(2)	29(1)	32	93
	a5D 2	3418.52	14.9(1)	13.9(7)		70
	a5G 2	4155.56	-	-		(50)L
	a5P 2	4474.63	12.5(2)	11.7(6)		
	a5P 1	4499.43	2.35(5)	2.2(1)		16
	b5D 0	4822.90	0.78(3)	0.73(4)		
	b5D 1	4860.55	0.91(3)	0.85(5)		
	a3P 0	4975.99	1.41(5)	1.32(8)		
	a3P 1	5417.36	3.08(9)	2.9(2)		9.3
	a3P 2	5609.35	1.39(4)	1.30(7)		
	a3D 1	5057.27	1.00(4)	0.93(6)		
	a3D 2	5062.50	2.45(6)	2.3(1)		7.0
	a5F 2	6960.61	1.40(6)	1.31(8)		4.0
	b3P 0	7016.42	1.03(5)	0.96(6)		4.0
	b3P 1	6999.13	1.24(5)	1.16(7)		4.3
	b3D 2	7171.75	0.52(4)	0.49(4)		

Table 2 (*Contd*)

UPPER LEVEL Energy Lifetime	LOWER LEVEL	λ (Å)	BRANCHING RATIO (%)	TRANSITION PROBABILITY (10^6 s^{-1}) This work	(a)	(b)
x5Do 2	a5S 2	3325.67	36.4(5)	16.6(9)	13	64
40829 K	a5D 1	3367.62	0.45(3)	0.21(2)		
22.0(1.)ns	a5D 2	3403.35	5.78(7)	2.7(1)		12
	a5D 3	3450.82	0.91(4)	0.41(3)		
	a3G 3	4142.04	0.94(4)	0.43(3)		
	a5P 3	4423.61	21.4(4)	9.8(5)		38
	a5P 1	4473.18	`11.3(4)	5.1(3)		24
	b5D 1	4829.93	2.20(6)	1.00(6)		
	b5D 2	4865.34	0.42(3)	0.20(2)		
	b5D 3	4881.86	0.73(3)	0.34(2)		
	a3P 1	5379.35	0.45(3)	0.21(2)		
	a3P 2	5568.61	5.7(2)	2.6(1)		6
	a3D 1	5024.13	0.29(4)	0.13(2)		
	a3D 2	5029.29	0.57(4)	0.26(2)		
	a3F 3	5825.64	0.56(4)	0.26(2)		
	a3F 2	5780.62	0.81(5)	0.36(3)		
	c5D 3	6611.19	3.0(1)	1.4(1)		2.6
	c5D 2	6649.67	1.21(7)	0.55(4)		
	a5F 3	6829.01	2.6(1)	1.2(1)		
	a5F 2	6897.99	2.3(1)	1.04(7)		
	b3P 1	6935.81	0.47(3)	0.22(2)		
	b3D 3	7045.27	1.03(4)	0.46(3)		2.4
	b3D 2	7105.29	0.42(4)	0.20(2)		
y5Fo 1	a5S 2	3305.60	15.1(4)	16.8(8)	17	100
41012 K	a5D 0	3327.30	25.2(3)	28(1)	28	113
9.0(4)ns	a5D 1	3347.00	23.3(3)	26(1)	27	100
	a5D 2	3382.29	4.60(8)	5.1(2)	4.8	20
	a5G 2	4102.14	11.6(4)	12.9(7)	15	73
	a5P 2	4412.76	5.8(2)	6.5(3)	7.7	33
	a5P 1	4436.87	4.1(1)	4.5(2)	5.4	33
	b5D 0	4751.10	0.58(3)	0.64(4)	0.98	
	b5D 1	4787.62	1.02(4)	1.13(7)	1.2	
	b5D 2	4822.41	1.55(5)	1.7(1)	1.9	5
	a3P 0	4899.60	1.00(7)	1.12(9)	1.4	
	a3P 2	5512.45	0.29(4)	0.32(5)		
	a3D 1	4978.37	0.4(2)	0.4(2)		
	a3D 2	4983.44	1.16(5)	1.29(8)	1.3	
	a3F 2	5720.13	0.2(1)	0.3(2)		
	a5F 2	6812.03	0.7(1)	0.8(2)		4
	a5F 1	6787.95	0.5(1)	0.5(1)		3.1
	b3P 1	6848.91	2.1(1)	2.3(1)		6.3
	b3D 2	7014.11	0.52(6)	0.58(6)		
	b3D 1	7324.42	0.3(1)	0.31(9)		
y5Fo 2	a5S 2	3303.34	1.7(1)	2.4(2)	2.9	(5)h
41032 K	a5D 1	3344.73	42(4)	59(5)	67	240
7.1(3) ns	a5D 2	3379.97	28(2)	40(4)	48	184
	a5D 3	3426.79	3.6(2)	5.0(4)	6.0	32
	a5G 2	4098.73	2.2(1)	3.1(3)	4.4	26
	a5G 3	4107.47	15(1)	21(2)	31	130
	a5P 3	4384.20	0.49(3)	0.70(6)	0.80	
	a5P 1	4432.88	0.21(2)	0.30(3)	0.46	
	b5D 1	4782.98	1.03(7)	1.4(1)		8.8
	b5D 2	4817.70	1.36(9)	1.9(1)	2.7	4.4
	b5D 3	4833.90	2.4(2)	3.3(3)		4.4
	a3D 1	4973.35	0.83(6)	1.2(1)	1.6	3.2
	a3G 3	4977.66	0.50(6)	0.71(8)	1.0	
	a3F 3	5757.48	0.17(2)	0.24(3)		
	a5F 2	6802.63	0.29(3)	0.41(4)		
	a5F 1	6778.62	0.49(5)	0.69(7)		
y5Fo 3	a5D 2	3358.12	58(4)	73(5)	90	229
41224 K	a5D 3	3404.34	17(1)	21(2)	28	93
8.0(2) ns	a5D 4	3461.84	0.27(3)	0.33(3)		
	a5G 2	4066.65	0.29(3)	0.36(4)		
	a5G 3	4075.25	3.1(3)	3.9(4)		26
	a5G 4	4084.37	18(2)	22(2)	40	126
	b5D 2	4773.44-	2.9(3)	3.6(3)		9.9
	b5D 3	4789.34	0.38(4)	0.48(5)		
	a3D 2	4931.16	0.50(4)	0.63(6)		
	a3F 3	5694.38	0.31(3)	0.39(4)		
y5Fo 5	a5D 4	3447.12	66(2)	87(4)	161	309
41348 K	a5G 4	4063.90	0.17(1)	0.22(2)		
7.6(3)ns	a5G 5	4069.99	3.6(2)	4.7(3)		d
	a5G 6	4069.89	25(2)	33(3)	44	200d
	b4D 4	4717.93	3.8(3)	5.0(4)		18
	a3G 5	4997.47	0.11(1)	0.13(2)		
	a5F 5	6474.00	0.41(3)	0.54(5)		1.7
	a5F 4	6512.69	0.20(2)	0.26(3)		
y5Fo 4	a5D 3	3384.61	61(4)	68(5)	82	222
41396 K	a5D 4	3441.45	7.6(7)	8.4(8)		31
9.0(3) ns	a5G 4	4056.01	3.7(4)	4.1(4)		30
	a5G 5	4062.09	21.(2)	24(2)		144
	a5P 3	4315.40	0.24(3)	0.27(3)		
	b5D 3	4750.39	4.2(4)	4.7(5)		11
	a3G 5	4985.55	0.80(8)	0.89(9)		2.2
	a3F 4	5591.60	0.3(1)	0.4(2)		
	c5D 3	6372.38	0.20(2)	0.23(3)		
	a5F 4	6492.46	0.28(3)	0.31(4)		

Table 2 (*Contd*)

UPPER LEVEL Energy Lifetime	LOWER LEVEL	λ (Å)	BRANCHING RATIO (%)	TRANSITION PROBABILITY (10^6 s^{-1}) This work (a)	(b)
y3Fo 2	a5D 1	3294.84	6.4(5)	3.6(3)	28
41485 K	a5D 2	3329.03	5.4(6)	3.0(3)	
18.0(5) ns	a5G 2	4024.07	9.1(3)	5.1(2)	34
	a5G 3	4032.49	1.8(3)	1.0(2)	8.4
	.a5P 3	4298.88	1.46(4)	0.81(3)	6.6
	a5P 1	4345.68	0.24(5)	0.13(3)	
	b5D 1	4681.62	0.59(4)	0.33(2)	
	b5D 3	4730.39	0.36(3)	0.20(2)	
	a3P 1	5196.03	0.28(3)	0,16(2)	
	a3P 2	5372.39	3.61(9)	2.01(8)	5.6
	a3D 1	4863.85	0.23(3)	0.13(2)	
	a3D 2	4868.69	0.86(4)	0.48(2)	
	a3D 3	5032.34	0.51(5)	0.28(3)	
	a3G 3	4867.98	59.5(7)	33(1)	70
	a3F 3	5611.24	0.61(4)	0.34(2)	
	a3F 2	5569.46	4.1(1)	2.3(1)	4.6
	c5D 2	6371.77	0.23(5)	0.13(3)	
	a5F 3	6536.25	0.88(4)	0.49(3)	
	b3P 1	6634.03	0.41(3)	0.23(2)	
	b3P 2	7105.73	1.11(7)	0.62(5)	
	b3D 2	6788.91	0.95(5)	0.53(3)	2.2
	b3D 1	7079.20	0.29(7)	0.16(4)	
	b3F 2	6946.82	1.09(7)	0.60(4)	1.4
y3Fo 3	a5D 2	3289.01	-	-	(186)i
41850 K	a5D 3	3333.33	1.08(4)	0.63(3)	
17.1(5) ns	a5D 4	3388.44	2.44(8)	1.43(6)	
	a5G 2	3965.73	1.05(5)	0.61(4)	5.7
	a5G 3	3973.91	5.6(1)	3.3(1)	19
	a5G 4	3982.58	1.57(3)	0.92(3)	5.7
	b5D 2	4635.00	0.83(4)	0.48(2)	
	b5D 4	4608.69	1.67(5)	0.98(4)	4.7
	a3P 2	5268.92	1.31(8)	0.77(5)	
	a3G 4	4830.47	74.(2)	44(2)	63
	a3F 3	5498.46	4.2(2)	2.5(1)	3.6
	a3F 2	5458.34	0.63(4)	0.37(3)	
	a5F 3	6383.73	0.44(3)	0.26(2)	
	b3P 2	6925.84	0.81(5)	0.47(3)	
	a1G 4	6571.01	0.41(4)	0.24(2)	
	b3D 2	6624.52	1.40(9)	0.82(6)	1.6
	b3F 3	7102.59	1.6(1)	0.90(6)	2.3
y3Fo 4	a5D 3	3307.78	16.3(5)	11.8(5)	46
42082 K j	a5D 4	3361.36	17.6(5)	12.7(6)	37
13.8(5) ns	a5G 3	3936.73	0.45(2)	0.33(2)	
	a5G 4	3945.24	1.54(3)	1.12(4)	9.4
	a5G 5	3950.98	1.81(4)	1.31(5)	9.4
	b5D 3	4599.15	1.96(4)	1.42(6)	6.2
	b5D 4	4558.75	0.96(3)	0.70(3)	3.9
	a3G 3	4729.11	7.6(2)	5.5(2)	13
	a3G 4	4775.64	4.24(8)	3.1(1)	8.1
	a3G 5	4819.22	41(1)	29(1)	52
	a3F 4	5383.22	0.23(1)	0.16(1)	
	a3F 3	5427.53	0.84(3)	0.61(3)	1.3
	a3H 4	5556.69	2.60(5)	1.88(8)	3.0
	a5F 4	6213.22	0.37(2)	0.27(2)	
	b3D 3	6471.23	1.0(1)	0.75(8)	
	b3F 3	6984.68	0.37(3)	0.27(3)	
	b3F 4	6980.39	0.96(5)	0.69(4)	1.4
	b3G 5	6961.45	0.59(3)	0.42(3)	
z3Ho 4	a5D 3	3296.41	3.9(2)	2.3(2)	16
42186 K	a5D 4	3350.30	5.9(2)	3.5(3)	
17.0(1.)ns	a5G 5	3935.70	0.62(3)	0.37(3)	
	b5D 3	4578.46	1.33(3)	0.78(5)	
	b5D 4	4538.42	0.48(3)	0.28(2)	
	a3D 3	4860.74	1.50(2)	0.88(6)	
	a3G 3	4707.23	68(1)	40(3)	k
	a3G 4	4753.33	0.52(2)	0.31(2)	
	a3G 5	4796.50	1.24(3)	0.73(5)	13
	a3F 4	5354.89	6.1(2)	3.6(2)	9.3
	a3F 3	5398.73	0.45(2)	0.27(2)	
	a3H 4	5526.51	3.7(1)	2.2(1)	4.9
	a3H 5	5641.73	0.30(2)	0.17(2)	
	a5F 4	6175.51	0.27(4)	0.16(3)	
	a1G 4	6429.08	0.65(4)	0.38(3)	
	b3F 3	6937.06	0.43(5)	0.26(4)	
	b3G 3	6753.94	4.4(1)	2.6(2)	5.9
z3Ho 5	b5D 4	4518.44	1.1(1)	0.61(7)	2.6
42283 K	a3G 4	4731.42	81(2)	45(3)	76
18.1(1.)ns	a3G 5	4774.20	2.4(2)	1.3(1)	4.2
	a3F 4	5327.10	1.6(2)	0.88(9)	3.2
	a3H 4	5496.92	0.31(4)	0.17(3)	1.3
	a3H 5	5610.89	8.6(8)	4.8(5)	10
	a1G 4	6389.07	1.0(1)	0.57(6)	1.9
	b3F 4	6886.32	3.0(3)	1.7(2)	3.3
	b3G 4	6691.06	0.54(5)	0.30(3)	0.59
z3Ho 6	a5G 5	3911.20	0.18(2)	.096(10)	d
42345 K	a5G 6	3911.10	0.83(2)	0.45(3)	6.9d
18.5(1.)ns	a3G 5	4760.16	87(1)	47(3)	72
	a3H 5	5591.51	0.48(7)	0.26(4)	1.7
	a3H 6	5705.69	6.6(1)	3.6(2)	7.2
	a5F 5	6081.26	0.49(2)	0.27(2)	0.92
	b3G 5	6838.88	4.5(1)	2.4(1)	5.2

Notes to Table 2.

a. Schnehage et al[9]

b. Corliss and Bozman[10]

c. λ6409.08: observed line may be a blend with $b^3D_3 - w^5D^o_2$.

d. Corliss and Bozman[10] do not resolve these two lines.

e. λ4950.62: observed line may be a blend with $a^3G_4 - y^5F^o_5$.

f. λ6471.15: Corliss and Bozman[10] do not resolve this line from $b^3D_3 - y^3F^o_4$ and assign the blend to $a^3F_2 - z^5G^o_2$.

g. λ4814.46: observed line may be a blend with $a^5S_2 - y^7P^o_3$. Corliss and Bozman[10] assign this line to the $y^7P^o_3$ upper level.

h. λ3303.34: Corliss and Bozman[10] assign this line to $a^5G_3 - 9^o$.

i. λ3289.01: Corliss and Bozman[10] assign this line to $a^5D_2 - y^3F^o_3$. We believe it should be assigned to $a^5D_4 - w^5D^o_4$.

j. This level energy listed incorrectly in Atomic Energy Levels[8]. Assigned energy of 42067.59 K based on wavelengths measured in this experiment.

k. λ4707.23: Corliss and Bozman[10] assign this line to $b^5D_4 - y^5F^o_4$. Measured λ indicates $a^3G_3 - z^3H^o_4$.

l. Corliss and Bozman[10] assign this line to $a^5G_2 - x^5D^o_1$. On the basis of lifetime measurments, we believe it should be assigned $a^3P_1 - x^3D^o_2$.

m. Lifetime derived from fluorescence of the λ4396.65 transition. On the basis of the longer lifetime (twice that of other levels in the z^5G term), and the lower population (one-eighth that of the other z^5G levels), we are led to question the assignment of this transition.

If the measured sum $\Sigma_l I_{ul}$ includes all transitions by which the level u decays, the experimental R_{ul} may be used to extract individual transition probabilites from the upper level lifetime τ_u: $A_{ul} = R_{ul}/\tau_u$. In this experiment the line intensity I_{ul} was measured on emission spectra (2900–10000 Å) recorded with the 1-m Fourier transform spectrometer[6] at Kitt Peak National Observatory. The FTS mirrors scanned through 13.6 cm to provide a theoretical resolution of 0.044 K, and the width of the observed line profiles was 0.10 K (FWHM). Although the high resolution offers good protection from blends, we also examined an Fe + Ar hollow-cathode spectrum to ensure that no Ar lines were coincident with the Mo lines of interest.

The spectral source was a hollow-cathode discharge (HCD) in argon. The water-cooled cathode, 8 mm inner diameter by 30 mm long, was fashioned from 99.992% molybdenum and no impurity lines have been detected in the spectrum. High-purity argon (99.999%) flowed continuously through the discharge chamber at 1.8 torr pressure.

Spectra were recorded at various HCD power levels to test for self-absorption: one at 520 mA/220 V; a second at 75 mA/327 V, and a third at 820 mA/184 V. All decay branches were measured on the first two spectra except for those lines too weak to be seen on the second spectrum. The third spectrum displayed self-reversal of the strong transitions to the ground term, and it was used only to search for the weakest branches from levels at high excitation energy. The intensity of lines in the second spectrum was a factor of 10–12 weaker than in the first, the exact value of the ratio depending on the excitation energy of the upper level. For a particular upper level, this intensity ratio must be constant for all decay channels, and the constancy of this ratio was used as a test for self-absorption.

The area under the line profile on the transformed spectrum was integrated over ±10 FWHM on either side of the line center to obtain the observed line intensity. The correction of the observed line intensity for the response of the FTS, and the method of determining the response function, has been described in detail earlier.[7] The branching ratio is then computed from Eq. (1). The uncertainty in the branching ratio includes contributions for the observed line areas and the FTS response function.

Determination of accurate transition probabilities from lifetimes requires that the sum $\Sigma_l I_{ul}$ in Eq. (1) include all transitions that contribute significantly to the decay of the level. We have computed the wavelength of all electric dipole transitions from the levels in Table 2 to lower levels listed in the Atomic Energy Levels[8] and searched our strongest spectrum (the third spectrum mentioned above) for the appearance of these lines. All lines found in the search were then measured on the weaker spectra. We were able to see lines with branching ratios down to the 0.1% level, and we conclude that branches too weak to be seen do not contribute significantly to the sum above.

Branches with $\lambda > 10{,}000$ Å were not recorded on our spectra, and one must ask if unobserved IR branches might contribute to the sum. None of the levels that we have studied have properties that would favor IR transitions to high excitation levels. The upper levels in Table 2 have configurations $(4d)^5 5p$ and $(4d)^4 5s5p$ and there are many levels with configurations $(4d)^5 5s$ and $(4d)^4(5s)^2$ at low energy that are accessible by a rapid $5p$–$5s$ transition.

We have examined an FTS spectrum from the KPNO archives of a Mo + Ar HCD that covers the wavelength range 10,000–40,000 Å. We searched for the strongest expected lines from the levels in Table 2 and found only one: λ11431, $b^5D_0 - z^5P_1^0$. We are not able to compare the intensity of this line with that of measured branches ($\lambda < 10{,}000$ Å) from the $z^5P_1^0$ level, but we have independent evidence that this line does not contribute greatly to the total decay strength of $z^5P_1^0$: the solar abundance derived from λ5570 from the $z^5P_1^0$ level agrees within experimental error with our mean Mo abundance.[1] λ11431 was neglected in the computation of the branching ratio for λ5570 and the abundance agreement is consistent with our assumption that λ11431 is negligible in the decay of the $z^5P_1^0$ level.

4. RESULTS

The measured lifetimes, branching ratios, and transition probabilities are presented in Table 2. The quoted uncertainty in the transition probability includes the combined effects of the uncertainty in τ and R and is typically $< 5\%$ for medium and strong branches. In the last two columns we show the recent measurements of Schnehage *et al.*[9] and the values of Corliss and Bozman.[10] The agreement with Schnehage *et al.* is good, as may be seen from Fig. 1 where we plot log[A(Schnehage)/A(this work)] as solid circles. The Schnehage *et al.* absolute scale is based on the lifetime measurements of Kwiatkowski *et al.*[4,5] for the

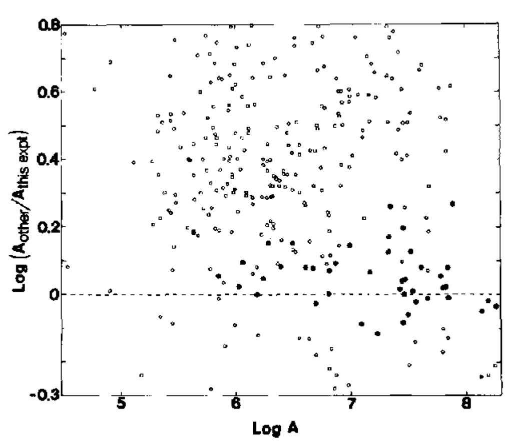

Fig. 1. Comparison of our measured transition probabilities A (this work) with values measured by others. The open circles represent the values of Corliss and Bozman;[10] the solid circles refer to recent measurements of Schnehage *et al.*[9]

levels $z^7P_4^0$, $z^5P_2^0$, and $y^5F_1^0$, and our lifetimes for these reference levels are in good agreement with those of Kwiatkowski *et al.* (see Table 1). Schnehage *et al.* measured the transition probability for lines from these reference levels by the same method used in this experiment and their results are in excellent agreement with ours. For other levels Schnehage *et al.* compared the relative intensity of emission lines from the same upper level and the relative intensity of absorption lines from the same lower level to project their absolute normalization by the so-called "leapfrog" method. The transition probabilities measured from absorption ratios are generally in good agreement with our values except for transitions from levels $z^5H_5^0$, $x^5D_1^0$ and $y^5F_5^0$. For these levels Schnehage *et al.* find transition probabilities greater than ours and thus would predict lifetimes for these levels that are somewhat shorter than our measured values.

The comparison with Corliss and Bozman in Fig. 1 shows considerable spread. For several lines noted in the footnotes to Table 2, our diagreement with Corliss and Bozman stems from their inability to resolve closely spaced lines or from a different assignment of the observed line.

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Author note added in proof:

Dr. J.W. Brault of K.P.N.O. has informed us that the level at 39600 K, identified as $z^5H_7^o$ in reference 8, actually has J = 6. Consequently, the branching ratios for the 39600 K level in Table 2 are incorrect. Dr. Brault's measurements confirm our belief that the λ4396.65 transition does not come from a level at 39522 K (see note m to Table 2).