NBS TECHNICAL NOTE

474

Critically Evaluated Transition Probabilities for Ba I and II

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards

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Critically Evaluated Transition Probabilities

for Ba I and II*

B. M. Miles and W. L. Wiese

Critically evaluated transition probabilities, in order of increasing quantum numbers, are compiled for Ba I and II from available literature sources.

Key words: Ba I, Ba II, line strengths, oscillator strengths, transition probabilities

This special compilation of critically evaluated transition probabilities of Ba I and II has been carried out in response to much recent interest in the barium spectrum. We have for the arrangement of these tables adopted the same format as used in our general compilations of atomic transition probabilities for the first[1] and second ten elements.[2] Thus we follow in our coding exactly the notation used in the other compilations. For convenience, we have collected below the special notation used in the evaluation of these two spectra.

Special Notation used in the Tables:

1. Multiplet column:

   Numbers in parenthesis are the multiplet numbers of Ref. 3 and 4.

2. Wavelength column:

   Wavelengths in brackets are calculated wavelengths rather than observed ones.

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3. Accuracy column:

B - for uncertainties within 10%
C - for uncertainties within 25%
D - for uncertainties wtihin 50%
E - for uncertainties larger than 50%.

4. Literature column:

n - indicates the values have been normalized to a basis which is different from the one chosen by the author.

ℓs - relative values obtained from LS-coupling tables.

REFERENCES

[1] Wiese, W.L., Smith, M.W., and Glennon, B.M., "Atomic Transition Probabilities-Hydrogen through Neon", NSRDS-NBS 4 Vol. 1 (1966) (U.S. Government Printing Office, Washington, D.C.).

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[3] Moore, C.E., "A Multiplet Table of Astrophysical Interest Revised Edition," National Bureau of Standards Tech. Note 36 (1959) (U.S. Government Printing Office, Washington, D.C.).

[4] Moore, C.E., "An Ultraviolet Multiplet Table," National Bureau of Standards Circular 488, Sec. 3 (1962) (U.S. Government Printing Office, Washington, D.C.).

BARIUM I

Ba I

Ground State $4s^2 4p^6 4d^{10} 5s^2 5p^6 6s^2\ {}^1S_0$

Ionization Potential $5.210\ eV = 42032.4\ cm^{-1}$

Allowed Transitions

List of tabulated lines:

Wavelength [Å]	No.	Wavelength [Å]	No.	Wavelength [A]	No.
2409.98	36	4323.00	44	5971.70	6
2414.83	35	4325.15	40	5997.09	6
2420.85	34	4332.91	44	6019.47	6
2428.17	33	4350.33	38	6063.12	6
2433.28	25	4402.54	41	6110.78	6
2439.55	32	4406.85	40	6341.68	5
2445.38	24	4431.89	38	6450.85	5
2453.12	31	4467.09	39	6482.91	9
2473.20	30	4488.98	44	6498.76	5
2500.2	29	4493.64	44	6527.31	5
2543.2	28	4505.92	38	6595.33	5
2596.64	22	4523.17	38	6675.27	5
2646.50	27	4573.85	38	6693.84	5
2702.63	21	4579.64	41	6865.69	8
2739.24	20	4591.82	13	7059.94	3
2785.28	26	4599.75	37	7120.33	4
3071.58	23	4604.98	13	7195.24	43
3501.11	17	4619.92	45	7280.30	3
3889.33	16	4628.33	13	7392.41	43
3909.91	1	4673.62	13	7417.53	4
3935.72	1	4691.62	38	7488.08	3
3937.87	1	4700.43	45	7672.09	3
3993.40	1	4726.44	14	7780.48	3
3995.66	1	5535.48	19	7905.75	43
4132.43	15	5777.62	42	7911.38	18
4239.56	46	5800.23	42	15000	11
4242.61	40	5805.69	7	27751	12
4264.42	44	5826.30	10	29224	12
4283.10	2	5907.64	6		

Aside from the principal resonance line and several other lines of the resonance series, the oscillator strength situation for Ba I is quite poor and needs drastic improvement.

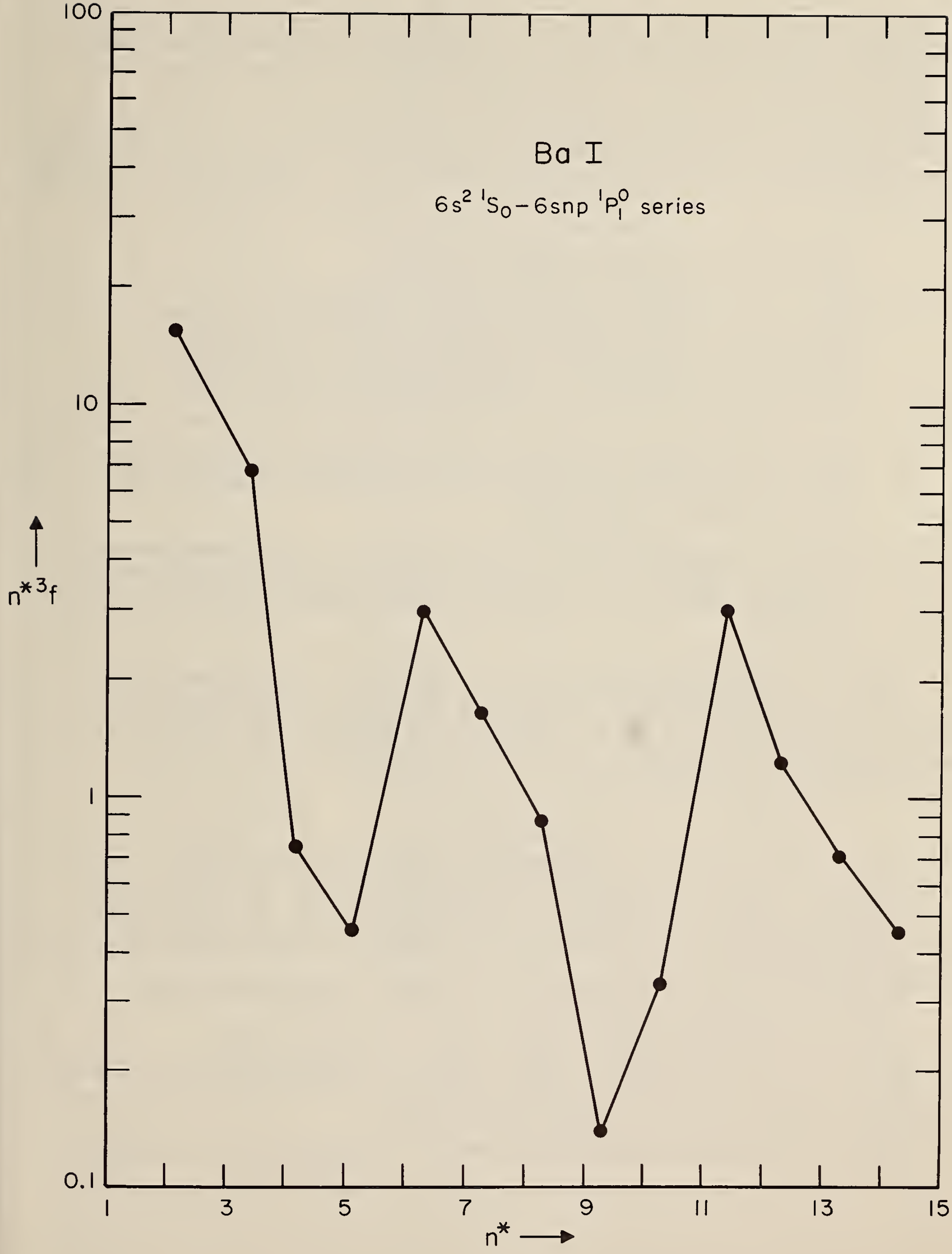
The adopted value for the principal resonance line is based on the lifetime measurements of the 6s6p $^1P_1$ state by Swagel and Lurio [1] with the Hanle-effect method (τ = 8.37 nsec) and by Hulpke, Paul and Paul [2] with the phase-shift technique (τ = 8.36 nsec). For converting this number to a transition probability, the small contribution of the 6s5d $^1D_2$ - 6s6p $^1P_1$ transition has to be considered, for which only a rough estimate is available from a Stark effect measurement by Paul (see Ref. [2]). The "hook measurements" of Prokof'ev [3] as well as Ostrovskii and Penkin [4] and the semi-empirical calculations by Vainshtein and Poluektov [5] have been employed for obtaining a relative f-value for the intercombination line 6s^2 $^1S_0$ - 6s6p $^3P_1$. This number should also be fairly accurate since the three determinations agree within 16 percent. We have furthermore deduced the f-values for the infrared 6s5d $^3D_{1,2}$ - 6s6p $^3P_1$ transitions from the lifetime measurement of Bucka and Nagel [6] for the 6s6p $^3P_1$ state by applying the above determined value for the intercombination line and by using the LS-coupling ratios.

The transitions of the resonance series 6s^2 ^1S - 6snp ^1P have been studied by Penkin and Shabanova [7] for the levels n=6 up to n=18 by employing the "hook" method. The authors find a highly irregular series behavior which is graphically presented in Figure 1. Most likely, perturbations of the upper states by other neighboring ^1P states are responsible for this. The accuracy of their results, which are normalized for the principal resonance line against the above mentioned lifetime, is estimated to be within 50 percent.

Various other transitions have been studied by Ostrovskii and Penkin [4] with the "hook" method, and by Eicke [8] with a vortex-stabilized arc. Also, Warner [9] has calculated the f-values of a few ns-mp transitions with the scaled Thomas-Fermi method, accounting for configuration mixing effects.

Ostrovskii and Penkin's numbers are relative f-values, which we have normalized against the resonance line using the earlier discussed accurate lifetime results. Eicke obtains absolute f-values, but they cannot be directly linked to the resonance line which he has not measured.

The results of the three authors differ greatly, often by factors of two and much more. We have therefore performed some extensive analyses to search for causes of the discrepancies. For example, we have plotted the ratios of Eicke's f-values against Ostrovskii and Penkin's f-values as a function of upper and lower energy levels as well as wavelengths. None of these have revealed any clear systematic trends, however, we noticed that there may be some indication of a systmatic dependence in Eicke's values. Namely, his f-values become drastically smaller relative to the "hook" results for some of the lines involving very high upper energy levels. In the Ostrovskii and Penkin experiment, on the other hand, only the populations of the lower energy levels come into play and



Ba I
6s2 1S0 – 6snp 1P1 0 series
100
10
1
0.1
n*3f
1
3
5
7
9
11
13
15
n*

for these no apparent trend could be noticed. Furthermore, the greatest uncertainties in Eicke's method lie in finding the absolute scale while his relative values should be much more accurate. We find indeed that a shift of his absolute scale by enlarging all his values by about a factor of two would bring at least half of his f-values into a 50 percent agreement with Ostrovskii and Penkin's normalized values. We have finally adopted Ostrovskii and Penkin's data because of the following main reasons:

a) These data may be directly linked up with the precise lifetime results for the resonance line.

b) The "hook" method is a time proven method, which has in many other instances given reliable results, while the method used by Eicke has been only applied in two other experiments. (However, it must be stated that in at least one of the other two experiments, which we have analyzed in detail, Eicke's method gives reliable results.)

c) Uncertainties in the temperature measurement should be somewhat less critical for Ostrovskii and Penkin's experiment than for Eicke's experiment.

d) The few calculated data do not appear to be too trustworthy, either, since they do not even agree well with experiment on a relative scale, for which the measurements should be fairly accurate.

Since we expect that temperature errors will be quite sensitive even in the adopted Ostrovskii and Penkin experiment, we estimate the overall uncertainties not to be much below 50 percent, but even this figure cannot be considered as too well established because of the presently existing discrepancies.

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No.	Transition Array	Multiplet	λ(Å)	$E_i(cm^{-1})$	$E_k(cm^{-1})$	g_i	g_k	$A_{ki}(10^8 s^{-1})$	f_{ik}	S(at.u.)	log gf	Accu.	L
1	6s5d - 6s(^{2}S)4f	^{3}D - ^{3}F° (8)											
			3993.40	9596.55	34630.8	7	9	0.55	0.17	16	0.08	D	4n
			3935.72	9215.52	34616.7	5	7	0.47	0.15	9.9	-0.12	D	4n
			3909.91	9033.99	34602.8	3	5	0.49	0.19	7.3	-0.25	D	4n
			3995.66	9596.55	34616.7	7	7	0.088	0.021	1.9	-0.83	D	4n
			3937.87	9215.52	34602.8	5	5	0.11	0.025	1.6	-0.90	D	4n
2		^{1}D - ^{1}F°	4283.10	11395.4	34736.4	5	7	0.64	0.25	17	0.09	D	4n
3	6s5d - 5d(^{2}S)6p'	^{3}D - ^{3}F° (5)											
			7059.94	9596.55	23757.1	7	9	0.71	0.68	110	0.68	D	4n
			7280.30	9215.52	22947.4	5	7	0.53	0.59	70	0.47	D	4n
			7672.09	9033.99	22064.7	3	5	0.31	0.45	34	0.14	D	4n
			7488.08	9596.55	22947.4	7	7	0.10	0.084	14	-0.23	D	4n
			7780.48	9215.52	22064.7	5	5	0.13	0.12	15	-0.23	D	4n
4		^{3}D - ^{1}D	7120.33	9033.99	23074.4	3	5	0.21	0.27	19	-0.10	D	4n
			7417.53	9596.55	23074.4	7	5	0.025	0.015	2.5	-0.98	D	4n
5		^{3}D - ^{3}D° (6)	6527.4	9357.02	24672.9	15	15	1.0	0.66	210	0.99	D	4n
			6498.76	9596.55	24979.9	7	7	0.86	0.55	82	0.58	D	4n
			6527.31	9215.52	24531.5	5	5	0.59	0.38	40	0.27	D	4n
			6595.33	9033.99	24192.1	3	3	0.72	0.47	31	0.15	D	4n
			6693.84	9596.55	24531.5	7	5	0.28	0.14	21	-0.02	D	4n
			6675.27	9215.52	24192.1	5	3	0.35	0.14	15	-0.15	D	4n
			6341.68	9215.52	24979.9	5	7	0.19	0.16	16	-0.11	D	4n
			6450.85	9033.99	24531.5	3	5	0.11	0.11	7.3	-0.47	D	4n

No.	Transition Array	Multiplet	λ(Å)	$E_i(cm^{-1})$	$E_k(cm^{-1})$	g_i	g_k	$A_{ki}(10^8 s^{-1})$	f_{ik}	S(at.u.)	log gf	Accu.	L
6		$^3D - ^3P°$ (7)	6066.1	9357.02	25837.5	15	9	1.4	0.45	140	0.83	D	4n
			6110.78	9596.55	25956.5	7	5	1.0	0.40	56	0.44	D	4n
			6063.12	9215.52	25704.1	5	3	0.97	0.32	32	0.21	D	4n
			6019.47	9033.99	25642.2	3	1	1.4	0.26	16	-0.10	D	4n
			5971.70	9215.52	25956.5	5	5	0.29	0.15	15	-0.11	D	4n
			5997.09	9033.99	25704.1	3	3	0.46	0.25	15	-0.12	D	4n
			5907.64	9033.99	25956.5	3	5	0.036	0.031	1.8	-1.03	D	4n
7		$^3D - ^1F°$											
			5805.69	9596.55	26816.3	7	7	0.040	0.020	2.7	-0.85	D	4n
8		$^1D - ^3P°$											
			6865.69	11395.4	25956.5	5	5	0.078	0.055	6.2	-0.56	D	4n
9		$^1D - ^1F°$	6482.91	11395.4	26816.3	5	7	0.44	0.39	42	0.29	D	4n
10		$^1D - ^1P°$	5826.30	11395.4	28554.3	5	3	0.97	0.30	28	0.17	D	4n
11	6s5d - 6s(^{2}S)6p	$^1D - ^1P°$	15000	11395.4	18080.3	5	3	0.049	0.10	25	-0.30	E	2
12		$^3D - ^3P°$											
			29224	9215.52	12636.6	5	3	0.00342	0.0263	12.7	-0.88	C	6, ℓs
			27751	9033.99	12636.6	3	3	0.00133	0.0154	4.22	-1.335	C	6, ℓs
13	6p5d - 6s(^{2}S)7p	$^3D - ^3P°$											
			4673.62	9596.6	30987.3	7	5	0.065	0.0015	1.6	-0.97	D	4n
			4628.33	9215.52	30815.6	5	3	0.060	0.012	0.88	-1.24	D	4n
			4604.98	9033.99	30743.5	3	1	0.077	0.0082	0.37	-1.61	D	4n
			4591.82	9215.52	30987.3	5	5	0.016	0.0052	0.39	-1.59	D	4n
14		$^1D - ^1P°$	4726.44	11395.4	32547.1	5	3	0.69	0.14	11	-0.16	D	4n
15	$6s^2$ - 5d(^{2}S)6p'	$^1S - ^3D°$	4132.43	0.00	24192.1	1	3	0.013	0.0099	0.13	-2.00	D	4n,7n

No.	Transition Array	Multiplet	λ(Å)	$E_i(cm^{-1})$	$E_k(cm^{-1})$	g_i	g_k	$A_{ki}(10^8 s^{-1})$	f_{ik}	S(at.u.)	log gf	Accu.	L
16		$^1S - ^3P°$	3889.33	0.00	25704.1	1	3	0.015	0.010	0.13	-1.99	D	4n,7n
17		$^1S - ^1P°$ (3)	3501.11	0.00	28554.3	1	3	0.29	0.16	1.9	-0.79	D	7n
18	$6s^2 - 6s(^2S)6p$	$^1S - ^3P°$ (1)	7911.38	0.00	12636.6	1	3	0.00353	0.00994	0.259	-2.00	C+	3,4,5
19		$^1S - ^1P°$ (2)	5535.48	0.00	18080.3	1	3	1.15	1.59	29.0	0.201	B	1,2
20	$6s^2 - 5d(^2S)7p'$	$^1S - ^3D°$	2739.24	0.00	36495.8	1	3	0.0091	0.0031	0.028	-2.51	D	7n
21		$^1S - ^3P°$	2702.63	0.00	36990.0	1	3	0.025	0.0081	0.072	-2.09	D	7n
22		$^1S - ^1P°$	2596.64	0.00	38499.9	1	3	0.12	0.035	0.30	-1.45	D	7n
23	$6s^2 - 6s(^2S)7p$	$^1S - ^1P°$ (4)	3071.58	0.00	32547.1	1	3	0.41	0.17	1.7	-0.76	D	7n
24	$6s^2 - 5d(^2S)8p'$	$^1S - ^3D$	2445.38	0.00	40893.4	1	3	0.0057	0.0015	0.012	-2.81	D	7n
25		$^1S - ^3P$	2433.28	0.00	41096.8	1	3	0.0095	0.0025	0.020	-2.60	D	7n
26	$6s^2 - 6s(^2S)8p$	$^1S - ^1P°$	2785.28	0.00	35892.5	1	3	0.028	0.0099	0.090	-2.01	D	7n
27	$6s^2 - 6s(^2S)9p$	$^1S - ^1P°$	2646.50	0.00	37774.5	1	3	0.011	0.0035	0.031	-2.45	D	7n
28	$6s^2 - 6s(^2S)10p$	$^1S - ^1P°$	2543.2	0.00	39308.7	1	3	0.041	0.012	0.099	-1.93	D	7n
29	$6s^2 - 6s(^2S)11p$	$^1S - ^1P°$	2500.2	0.00	39984.8	1	3	0.015	0.0043	0.035	-2.37	D	7n
30	$6s^2 - 6s(^2S)12p$	$^1S - ^1P°$	2473.20	0.00	40421.23	1	3	0.0057	0.0016	0.013	-2.81	D	7n
31	$6s^2 - 6s(^2S)13p$	$^1S - ^1P°$	2453.12	0.00	40764.4	1	3	$6.4x10^{-4}$	$1.7x10^{-4}$	0.0014	-3.76	D	7n
32	$6s^2 - 6s(^2S)14p$	$^1S - ^1P°$	2439.55	0.00	40991.2	1	3	0.0012	$3.3x10^{-4}$	0.0027	-3.48	D	7n
33	$6s^2 - 6s(^2S)15p$	$^1S - ^1P°$	2428.17	0.00	41183.3	1	3	0.0078	0.0021	0.017	-2.68	D	7n

No.	Transition Array	Multiplet	λ(Å)	$E_i(cm^{-1})$	$E_k(cm^{-1})$	g_i	g_k	$A_{ki}(10^8 s^{-1})$	f_{ik}	S(at.u.)	log gf	Accu.	L
34	$6s^2 - 6s(^2S)16p$	$^1S - ^1P°$	2420.85	0.00	41307.8	1	3	0.0025	$6.7x10^{-4}$	0.0053	-3.18	D	7n
35	$6s^2 - 6s(^2S)17p$	$^1S - ^1P°$	2414.83	0.00	41410.8	1	3	0.0012	$3.0x10^{-4}$	0.0024	-3.52	D	7n
36	$6s^2 - 6s(^2S)18p$	$^1S - ^1P°$	2409.98	0.00	41494.1	1	3	$6.1x10^{-4}$	$1.6x10^{-4}$	0.0013	-3.80	D	7n
37	$6s(^2S)6p - 6p^2$	$^3P° - ^1S$											
			4599.75	12636.6	34370.8	3	1	1.0	0.11	4.8	-0.50	D	4n
38		$^3P° - ^3P$	4514.6	13083.3	35227.6	9	9	2.5	0.77	100	0.84	D	4n
			4523.17	13514.7	35616.9	5	5	0.96	0.29	22	0.17	D	4n
			4505.92	12636.6	34823.4	3	3	1.1	0.32	14	-0.02	D	4n
			4691.62	13514.7	34823.4	5	3	1.6	0.33	25	0.21	D	4n
			4573.85	12636.6	34493.9	3	1	2.9	0.31	14	-0.04	D	4n
			4350.33	12636.6	35616.9	3	5	0.60	0.28	12	-0.07	D	4n
			4431.89	12266.0	34823.4	1	3	1.2	1.1	16	0.03	D	4n
39	$6s(^2S)6p - 5d(^2D)6d'$	$^3P° - ^3G$											
			4467.09	13514.7	35894.3	5	7	0.066	0.028	2.0	-0.86	D	4n
40		$^3P° - ^3D$	4325.15	13514.7	36628.9	5	7	0.071	0.028	2.0	-0.86	D	4n
			4242.61	12636.6	36200.4	3	5	0.056	0.025	1.1	-1.12	D	4n
			4406.85	13514.7	36200.4	5	5	0.10	0.030	2.2	-0.83	D	4n
41		$^3P - ^1D$											
			4579.64	13514.7	35344.4	5	5	1.8	0.56	42	0.45	D	4n
			4402.54	12636.6	35344.4	3	5	0.70	0.34	15	0.01	D	4n
42	$6s6p - 6s(^2S)6d$	$^3P - ^3D$ (9)											
			5777.62	13514.7	30818.1	5	7	1.5	1.0	99	0.72	D	4n
			5800.23	13514.7	30750.7	5	5	0.48	0.24	23	0.08	D	4n
43	$6s6p - 6s(^2S)7s$	$^3P° - ^3S$ (10)	7644.9	13083.3	26160.3	9	3	1.4	0.40	90	0.55	D	4n
			7905.75	13514.7	26160.3	5	3	0.63	0.35	46	0.25	D	4n
			7392.41	12636.6	26160.3	3	3	0.50	0.41	30	0.09	D	4n
			7195.24	12266.0	26160.3	1	3	0.24	0.56	13	-0.25	D	4n

No.	Transition Array	Multiplet	λ(Å)	E_i(cm^{-1})	E_k(cm^{-1})	g_i	g_k	A_{ki}(10^8s^{-1})	f_{ik}	S(at.u.)	log gf	Accu.	L
44	6s6p - 6s(^{2}S)7d	$^3P° - ^3D$											
			4488.98	13514.7	35785.3	5	7	0.42	0.18	13	-0.05	D	4n
			4323.00	12636.6	35762.2	3	5	0.15	0.072	3.1	-0.67	D	4n
			4264.42	12266.0	35709.3	1	3	0.15	0.13	1.8	-0.90	D	4n
			4493.64	13514.7	35762.2	5	5	0.36	0.11	8.1	-0.26	D	4n
			4332.91	12636.6	35709.3	3	3	0.15	0.043	1.9	-0.89	D	4n
45	6s6p - 6s(^{2}S)8s	$^3P° - ^3S$											
			4619.92	12266.0	33905.3	1	3	0.093	0.090	1.4	-1.05	D	4n
			4700.43	12636.6	33905.3	3	3	0.24	0.079	3.7	-0.63	D	4n
46	6s6p - 6s(^{2}S)9s	$^3P° - ^3S$											
			4239.56	13514.7	37095.5	5	3	0.24	0.038	2.7	-0.72	D	4n

BARIUM II

Ba II

Ground State $4s^2 4p^6 4d^{10} 5s^2 5p^6 6s\ ^2S_{1/2}$

Ionization Potential $10.001\ eV = 80686.87\ cm^{-1}$

Allowed Transitions

List of tabulated lines:

Wavelength [Å]	No.	Wavelength [Å]	No.	Wavelength [Å]	No.
1413.3	13	2200.9	25	4934.09	17
1417.2	12	2232.8	24	4997.81	41
1444.7	11	2235.4	24	5185.1	35
1461.3	11	2286.0	25	5361.35	31
1486.6	10	2528.40	22	5391.60	31
1503.9	10	2634.78	22	5413.6	2
1554.3	8	2641.37	22	5421.05	31
1572.7	8	2647.26	23	5428.79	2
1573.9	8	2771.35	23	5480.30	2
1630.4	19	3816.7	33	5784.18	38
1674.4	7	3842.8	33	5853.68	6
1694.3	7	3891.78	20	5981.25	38
1697.2	7	4024.1	4	5999.85	38
1761.7	9	4057.5	4	6135.83	39
1771.1	9	4130.65	20	6141.72	6
1787.0	9	4166.00	20	6363.2	16
1892.5	28	4287.80	43	6373.2	32
1904.16	5	4325.73	42	6378.91	39
1906.8	29	4329.62	42	6457.7	32
1924.77	5	4405.23	43	6496.90	6
1954.3	28	4470.7	3	7556.8	15
1955.1	28	4509.6	3	7678.3	15
1970.3	29	4524.93	21	8496.8	47
1985.7	26	4554.03	17	8591.4	1
1999.54	18	4616.04	42	8661.9	1
2009.3	27	4708.94	40	8703.7	47
2052.8	26	4843.46	40	8710.82	30
2054.1	26	4847.14	41	8719.1	47
2080.0	27	4850.84	40	8737.74	30
2153.9	24	4899.93	21	8760.6	1

Wavelength [Å]	No.	Wavelength [Å]	No.	Wavelength [A]	No.
8793.2	48	10768	45	11932	46
8897.5	30	10770	14	12475	37
9031.5	48	10994	14	13058	34
9603.3	36	11089	45	14211	34
10115	36	11127	45	18729	44
10213	36	11519	46	19643	44
10710	14	11577	37	19845	44

The most accurate f-values in this spectrum belong to the lines having the 6p ^2P levels as their upper states. Precise lifetime measurements of these states using the Hanle effect technique have been performed by Bucka et al. [1] and Gallagher [2], and are in close agreement. Bucka et al. obtain for the 6p $^2P_{3/2}$ level a lifetime of 7.0 ± 0.6 nsec, while Gallagher's result is 6.27 ± 0.25 nsec. We have utilized Gallagher's data exclusively, since he has also reduced the lifetime data to transition probabilities by measuring the relative strengths of all lines originating from the 6p ^2P upper levels, i.e., the branching ratios. For a number of vacuum uv lines and some visible transitions, von Specht [3] has determined moderately precise f-values - he estimates uncertainties of 35% - from emission measurements with a wall-stabilized arc operating in a barium-argon atmosphere. There is unfortunately no direct link between the data of von Specht and the presumably more accurate lifetime results of Gallagher. A somewhat indirect comparison via a few low current arc measurements by Kolesnikov and Slepchenko [4] gives the indication that von Specht's data may be somewhat high. However, Kolesnikov and Slepchenko's data cannot be considered very reliable since their f-values disagree quite badly with other results, even on a relative scale.

For many other lines of at least moderate strength we use the recent calculations by Warner [5]. Warner uses essentially the Coulomb approximation by Bates and Damgaard [6] with a modified potential and makes some allowance for configuration mixing and perturbation effects. Since Ba II is basically a one-electron spectrum this should be a reasonable approach if the jumping electron has a little interaction with the core. This is indeed indicated by the few available comparisons with the above mentioned experiments by Gallagher and von Specht, some of which are presented in Table I. It is seen that very pronounced differences exist for the 5d-6p transitions, which is clearly non-Coulombic. The agreement becomes then increasingly better as the jumping electron gets further away from the core, and is already quite acceptable for the 6s-6p transition. Some isolated cancellation seems to be apparent as indicated for example by the rather small theoretical gf-value for the 6s-8p transition. We have therefore limited our tabulation of Warner's f-values to those transitions which are either in the visible or near infrared (λ smaller than 20,000 Å) and which have gf-values larger than 10^{-3}.

Table I. Comparison of some Ba II f-values calculated by Warner on the basis of the Coulomb-approximation with experimental results by Gallagher (Hanle-effect) and von Specht (stabilized arc).

Transition	λ	Warner [5]	Gallagher [2]	v.Specht [3]
5d $^2D_{5/2}$ - 6p $^2P^\circ_{3/2}$	6141.72	0.12	0.14	-
$^2D_{3/2}$ - $^2P^\circ_{3/2}$	5853.68	0.017	0.025	-
$^2D_{3/2}$ - $^2P^\circ_{1/2}$	6496.90	0.087	0.105	-
5d $^2D_{3/2}$ - 8p $^2P^\circ_{3/2}$	1761.7	1.12×10^{-4}	-	1.8×10^{-4}
$^2D_{3/2}$ - $^2P^\circ_{1/2}$	1771.1	0.93×10^{-4}	-	7.9×10^{-4}
$^2D_{5/2}$ - $^2P^\circ_{3/2}$	1787.0	0.035×10^{-3}	-	1.4×10^{-3}
5d $^2D_{3/2}$ - 6f $^2F^\circ_{5/2}$	1674.4	0.38×10^{-6}	-	1.4×10^{-2}
$^2D_{5/2}$ - $^2F^\circ_{7/2}$	1694.3	0.096×10^{-2}	-	1.2×10^{-2}
$^2D_{5/2}$ - $^2F^\circ_{5/2}$	1697.2	0.26×10^{-4}	-	7.3×10^{-4}
5d $^2D_{3/2}$ - 7f $^2F^\circ_{5/2}$	1554.3	0.45×10^{-2}	-	1.4×10^{-2}
$^2D_{5/2}$ - $^2F^\circ_{7/2}$	1572.7	0.22×10^{-2}	-	1.2×10^{-2}
$^2D_{5/2}$ - $^2F^\circ_{5/2}$	1573.9	2.95×10^{-4}	-	5.8×10^{-4}
6s $^2S_{1/2}$ - 6p $^2P^\circ_{3/2}$	4554.03	0.78	0.74	
$^2S_{1/2}$ - $^2P^\circ_{1/2}$	4934.09	0.37	0.35	-
6s $^2S_{1/2}$ - 8p $^2P^\circ_{1/2}$	1630.4	0.018×10^{-4}	-	6.6×10^{-4}
6p $^2P^\circ_{3/2}$ - 6d $^2D_{5/2}$	4130.65	0.898	-	1.2
$^2P^\circ_{3/2}$ - $^2D_{3/2}$	4166.00	0.103	-	0.095
6p $^2P^\circ_{1/2}$ - 7s $^2S_{1/2}$	4524.93	0.145	-	0.22

References

[1] Bucka, H., Eichler, J. and Oppen, G., Z. Naturforsch. 21a, 654-656 (1966).

[2] Gallagher, A., Phys. Rev. 157, 24-30 (1967).

[3] von Specht, J., Max-Planck-Institut. für Physik und Astrophysik, MPI-PAE 4/68 (1968).

[4] Kolesnikov, N.S. and Slepchenko, N.S., Fiz. Probl. Spektroskopii, Akad, Nauk. S.S.S.R., Materialy 13-Go (Trinadtsatogo) Soveshch., Leningrad 41-43 (1962).

[5] Warner, B., Monthly Notices Roy. Astron. Soc. 139, 115-128 (1968).

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No.	Transition Array	Multiplet	λ(Å)	$E_i(cm^{-1})$	$E_k(cm^{-1})$	g_i	g_k	$A_{ki}(10^8 s^{-1})$	f_{ik}	S(at.u.)	log gf	Accu.	L
1	4f - $(^1S)7d$	$^2F° - ^2D$	8715.9	48387.0	59857.1	14	10	0.035	0.028	11	-0.40	D	5
			[8760.6]	48483.3	59895.0	8	6	0.031	0.027	6.2	-0.67	D	5
			[8661.9]	48258.6	59800.3	6	4	0.038	0.029	4.9	-0.77	D	5
			[8591.4]	48258.6	59895.0	6	6	0.0013	0.0015	0.25	-2.06	D	5
2	4f - $(^1S)8d$	$^2F° - ^2D$ (9)	5457.7	48387.0	66704.8	14	10	0.020	0.0065	1.6	-1.04	D	5
			5480.30	48483.3	66725.4	8	6	0.018	0.0061	0.89	-1.31	D	5
			5428.79	48258.6	66673.8	6	4	0.023	0.0067	0.72	-1.40	D	5
			[5413.6]	48258.6	66725.4	6	6	$8.4x10^{-4}$	$3.7x10^{-4}$	0.039	-2.66	D	5
3	4f - $(^1S)9d$	$^2F° - ^2D$											
			[4509.6]	48483.3	70651.9	8	6	0.012	0.0028	0.33	-1.65	D	5
			[4470.7]	48258.6	70620.4	6	4	0.014	0.0028	0.25	-1.77	D	5
4	4f - $(^1S)10d$	$^2F° - ^2D$											
			[4057.5]	48483.3	73122.2	8	6	0.012	0.0022	0.23	-1.76	D	5
			[4024.1]	48258.6	73101.9	6	4	0.0053	$8.6x10^{-4}$	0.068	-2.29	D	5
5	5d - $(^1S)5f$	$^2D - ^2F°$ (uv 4)											
			1924.77	5674.82	57631.6	6	8	0.031	0.0023	0.087	-1.86	D	3
			1904.16	4873.85	57390.9	4	6	0.011	$8.6x10^{-4}$	0.022	-2.46	D	3
6	5d - $(^1S)6p$	$^2D - ^2P°$ (2)	6234.9	5354.43	21388.8	10	6	0.389	0.136	27.9	0.134	C+	2
			6141.72	5674.82	219524	6	4	0.371	0.14	17.0	-0.076	C+	2
			6496.90	4873.85	20261.6	4	2	0.332	0.105	8.98	-0.377	C+	2
			5853.68	4873.85	21952.4	4	4	0.0487	0.025	1.93	-1.000	C+	2
7	5d - $(^1S)6f$	$^2D - ^2F°$	1686.4	5354.43	64653.9	10	14	0.22	0.013	0.73	-0.88	D	3
			[1694.3]	5674.82	64697.1	6	8	0.21	0.012	0.40	-1.14	D	3
			[1674.4]	4873.85	64596.3	4	6	0.22	0.014	0.31	-1.25	D	3
			[1697.2]	5674.82	64596.3	6	6	0.017	$7.3x10^{-4}$	0.024	-2.36	D	3

No.	Transition Array	Multiplet	λ(Å)	E_i(cm^{-1})	E_k(cm^{-1})	g_i	g_k	A_{ki}($10^8 s^{-1}$)	f_{ik}	S(at.u.)	log gf	Accu.	L
8	5d - (^{1}S)7f	^{2}D - ^{2}F°	1565.3	5354.43	69239.6	10	14	0.25	0.013	0.68	-0.88	D	3
			[1572.7]	5674.82	69260.5	6	8	0.24	0.012	0.37	-1.14	D	3
			[1554.3]	4873.85	69211.7	4	6	0.26	0.014	0.29	-1.25	D	3
			[1573.9]	5674.82	69211.7	6	6	0.016	5.8×10^{-4}	0.018	-2.46	D	3
9	5d - (^{1}S)8p	^{2}D - ^{2}P°	1779.9	5354.43	61536	10	6	0.043	0.0012	0.072	-1.91	D	3
			[1787.0]	5674.82	61636	6	4	0.044	0.0014	0.049	-2.08	D	3
			[1771.1]	4873.85	61336	4	2	0.034	7.9×10^{-4}	0.018	-2.50	D	3
			[1761.7]	4873.85	61636	4	4	0.0039	1.8×10^{-4}	0.0042	-3.14	D	3
10	5d - (^{1}S)8f	^{2}D - ^{2}F°											
			[1503.9]	5674.82	72170.2	6	8	0.15	0.0070	0.21	-1.38	D	3
			[1486.6]	4873.85	72142.7	4	6	0.14	0.0070	0.14	-1.55	D	3
11	5d - (^{1}S)9f	^{2}D - ^{2}F°											
			[1461.3]	5674.82	74108.9	6	8	0.087	0.0037	0.11	-1.65	D	3
			[1444.7]	4873.85	74091.0	4	6	0.081	0.0038	0.072	-1.82	D	3
12	5d - (^{1}S)10f	^{2}D - ^{2}F°											
			[1417.2]	4873.85	75438	4	6	0.038	0.0017	0.032	-2.17	D	3
13	5d - (^{1}S)11f	^{2}D - ^{2}F°											
			[1413.3]	5674.82	76429	6	8	0.017	6.7×10^{-4}	0.019	-2.40	D	3
14	5f - (^{1}S)8d	^{2}F° - ^{2}D	10895	57528.5	66704.8	14	10	0.0017	0.0022	1.1	-1.52	D	5
			[10994]	57631.6	66725.4	8	6	0.0011	0.0015	0.43	-1.92	D	5
			[10770]	57390.9	66673.8	6	4	0.0024	0.0028	0.60	-1.77	D	5
			[10710]	57390.9	66725.4	6	6	1.3×10^{-4}	2.3×10^{-4}	0.048	-2.87	D	5
15	5f - (^{1}S)9d	^{2}F° - ^{2}D											
			[7678.3]	57631.6	70651.9	8	6	6.6×10^{-4}	4.4×10^{-4}	0.089	-2.45	D	5
			[7556.8]	57390.9	70620.4	6	4	0.0016	9.3×10^{-4}	0.14	-2.25	D	5
16	5f - (^{1}S)10d	^{2}F° - ^{2}D											
			[6363.2]	57390.9	73101.9	6	4	0.0029	0.0012	0.15	-2.15	D	5

No.	Transition Array	Multiplet	λ(Å)	$E_i(cm^{-1})$	$E_k(cm^{-1})$	g_i	g_k	$A_{ki}(10^8 s^{-1})$	f_{ik}	S(at.u.)	log gf	Accu.	L
17	6s - (^1S)6p	^2S - $^2P°$ (1)	4674.0	0.00	21388.8	2	6	1.11	1.09	33.5	0.338	B	2
			4554.03	0.00	21952.4	2	4	1.19	0.74	22.2	0.170	B	2
			4934.09	0.00	20261.6	2	2	0.955	0.35	11.4	-0.155	B	2
18	6s - (^1S)7p	^2S - $^2P°$ (uv 1)	1999.54	0.00	50011.2	2	4	0.10	0.012	0.16	-1.61	D	5
19	6s - (^1S)8p	^2S - $^2P°$	[1630.4]	0.00	61336	2	2	0.017	6.6×10^{-4}	0.0071	-2.88	D	3
20	6p - (^1S)6d	$^2P°$ - ^2D (4)	4130.65	21952.4	46154.9	4	6	3.1	1.2	65	0.68	D	3
			3891.78	20261.6	45949.5	2	4	2.1	0.96	25	0.28	D	5
			4166.00	21952.4	45949.5	4	4	0.37	0.095	5.2	-0.42	D	3
21	6p - (^1S)7s	$^2P°$ - ^2S (3)	4899.93	21952.4	42355.2	4	2	1.2	0.21	13	-0.08	D	5
			4524.93	20261.6	42355.2	2	2	0.72	0.22	6.6	-0.36	D	3
22	6p - (^1S)7d	$^2P°$ - ^2D (uv 6)	2598.8	21388.8	59857.1	6	10	0.79	0.13	6.8	-0.10	D	5
			2634.78	21952.4	59895.0	4	6	0.76	0.12	4.1	-0.32	D	5
			2528.40	20261.6	59800.3	2	4	0.71	0.14	2.3	-0.56	D	5
			2641.37	21952.4	59800.3	4	4	0.12	0.012	0.43	-1.30	D	5
23	6p - (^1S)8s	$^2P°$ - ^2S (uv 5)	2728.7	21388.8	58025.2	6	2	0.60	0.022	1.2	-0.87	D	5
			2771.35	21952.4	58025.2	4	2	0.40	0.023	0.85	-1.03	D	5
			2647.26	20261.6	58025.2	2	2	0.20	0.021	0.36	-1.39	D	5
24	6p - (^1S)8d	$^2P°$ - ^2D	2206.0	21388.8	66704.8	6	10	0.40	0.049	2.1	-0.53	D	5
			[2232.8]	21952.4	66725.4	4	6	0.29	0.033	0.97	-0.88	D	5
			[2153.9]	20261.6	66673.8	2	4	0.53	0.074	1.0	-0.83	D	5
			[2235.4]	21952.4	66673.8	4	4	0.044	0.0033	0.097	-1.88	D	5

No.	Transition Array	Multiplet	λ(Å)	E_i(cm^{-1})	E_k(cm^{-1})	g_i	g_k	A_{ki}(10^8 s^{-1})	f_{ik}	S(at.u.)	log gf	Accu.	L
25	6p - (^{1}S)9s	^{2}P° - ^{2}S	2256.9	21388.8	65683.4	6	2	0.32	0.0083	0.37	-1.30	D	5
			[2286.0]	21952.4	65683.4	4	2	0.13	0.0052	0.16	-1.68	D	5
			[2200.9]	20261.6	65683.4	2	2	0.20	0.014	0.21	-1.54	D	5
26	6p - (^{1}S)9d	^{2}P° - ^{2}D	2029.8	21388.8	70639.3	6	10	0.23	0.024	0.94	-0.85	D	5
			[2052.8]	21952.4	70651.9	4	6	0.20	0.019	0.50	-1.13	D	5
			[1985.7]	20261.6	70620.4	2	4	0.25	0.030	0.39	-1.22	D	5
			[2054.71]	21952.4	70620.4	4	4	0.029	0.0018	0.049	-2.14	D	5
27	6p - (^{1}S)10s	^{2}P° - ^{2}S	2055.9	21388.8	70014.7	6	2	0.18	0.0039	0.16	-1.63	D	5
			[2080.0]	21952.4	70014.7	4	2	0.10	0.0033	0.089	-1.89	D	5
			[2009.3]	20261.6	70014.7	2	2	0.086	0.0052	0.069	-1.98	D	5
28	6p - (^{1}S)10d	^{2}P° - ^{2}D											
			[1954.3]	21952.4	73122.2	4	6	0.13	0.011	0.29	-1.35	D	5
			[1892.5]	20261.6	73101.9	2	4	0.090	0.0097	0.12	-1.71	D	3
			[1955.1]	21952.4	73101.9	4	4	0.018	0.0011	0.027	-2.38	D	5
29	6p - (^{1}S)11s	^{2}P° - ^{2}S	1948.7	21388.8	72705.3	6	2	0.12	0.0022	0.085	-1.88	D	5
			[1970.3]	21952.4	72705.3	4	2	0.067	0.0019	0.050	-2.11	D	5
			[1906.8]	20261.6	72705.3	2	2	0.051	0.0028	0.035	-2.26	D	5
30	6d - (^{1}S)5f	^{2}D - ^{2}F° (5)	8726.9	46072.7	57528.5	10	14	0.88	1.4	400	1.15	D	5
			8710.82	46154.9	57631.6	6	8	0.80	1.2	210	0.86	D	5
			8737.74	45949.5	57390.9	4	6	0.93	1.6	180	0.81	D	5
			[8897.5]	46154.9	57390.9	6	6	0.053	0.064	11	-0.42	D	5
31	6d - (^{1}S)6f	^{2}D - ^{2}F° (6)	5380.3	46072.7	64653.9	10	14	0.051	0.031	5.5	-0.51	D	5
			5391.60	46154.9	64697.1	6	8	0.052	0.030	3.2	-0.74	D	5
			5361.35	45949.5	64596.3	4	6	0.048	0.031	2.2	-0.91	D	5
			5421.05	46154.9	64596.3	6	6	0.0019	8.3×10^{-4}	0.089	-2.30	D	5

No.	Transition Array	Multiplet	λ(Å)	$E_i(cm^{-1})$	$E_k(cm^{-1})$	g_i	g_k	$A_{ki}(10^8 s^{-1})$	f_{ik}	S(at.u.)	log gf	Accu.	L
32	6d - $(^1S)8p$	$^2D - ^2P°$											
			[6457.7]	46154.9	61636	6	4	0.0030	0.0012	0.16	-2.13	D	5
			[6373.2]	45949.5	61636	4	4	$6.7x10^{-4}$	$4.1x10^{-4}$	0.034	-2.79	D	5
33	6d - $(^1S)8f$	$^2D - ^2F°$											
			[3842.8]	46154.9	72170.2	6	8	0.0022	$6.4x10^{-4}$	0.048	-2.42	D	5
			[3816.7]	45949.5	72142.7	4	6	0.0023	$7.5x10^{-4}$	0.037	-2.53	D	5
34	7s - $(^1S)7p$	$^2S - ^2P°$	13421	42355.2	49804.2	2	6	0.20	1.6	140	0.51	D	5
			[13058]	42355.2	50011.2	2	4	0.21	1.1	94	0.34	D	5
			[14211]	42355.2	49390.1	2	2	0.18	0.53	50	0.03	D	5
35	7s - $(^1S)8p$	$^2S - ^2P°$											
			[5185.1]	42355.2	61636	2	4	0.018	0.014	0.48	-1.55	D	5
36	7p - $(^1S)7d$	$^2P° - ^2D$	9944.6	49804.2	59857.1	6	10	0.44	1.1	210	0.82	D	5
			[10115]	50011.2	59895.0	4	6	0.45	1.0	140	0.62	D	5
			[9603.3]	49390.1	59800.3	2	4	0.35	0.96	61	0.28	D	5
			[10213]	50011.2	59800.3	4	4	0.077	0.12	16	-0.32	D	5
37	7p - $(^1S)8s$	$^2P° - ^2S$	12161	49804.2	58025.2	6	2	0.44	0.33	79	0.29	D	5
			[12475]	50011.2	58025.2	4	2	0.31	0.36	59	0.16	D	5
			[11577]	49390.1	58025.2	2	2	0.13	0.27	20	-0.27	D	5
38	7p - $(^1S)8d$	$^2P° - ^2D$ (13)	5915.3	49804.2	66704.8	6	10	0.19	0.16	19	-0.01	D	5
			5981.25	50011.2	66725.4	4	6	0.16	0.13	10	-0.29	D	5
			5784.18	49390.1	66673.8	2	4	0.20	0.20	7.6	-0.40	D	5
			5999.85	50011.2	66673.8	4	4	0.026	0.014	1.1	-1.26	D	5
39	7p - $(^1S)9s$	$^2P° - ^2S$ (12)	6295.8	49804.2	65683.4	6	2	0.18	0.036	4.5	-0.66	D	5
			6378.91	50011.2	65683.4	4	2	0.099	0.030	2.5	-0.92	D	5
			6135.83	49390.1	65683.4	2	2	0.085	0.048	1.9	-1.02	D	5

No.	Transition Array	Multiplet	λ(Å)	$E_i(cm^{-1})$	$E_k(cm^{-1})$	g_i	g_k	$A_{ki}(10^8 s^{-1})$	f_{ik}	S(at.u.)	log gf	Accu.	L
40	7p - (^1S)9d	$^2P° - ^2D$ (15)	4798.3	49804.2	70639.3	6	10	0.10	0.058	5.5	-0.46	D	5
			4843.46	50011.2	70651.9	4	6	0.093	0.049	3.1	-0.71	D	5
			4708.94	49390.1	70620.4	2	4	0.097	0.065	2.0	-0.89	D	5
			4850.84	50011.2	70620.4	4	4	0.014	0.0051	0.32	-1.69	D	5
41	7p - (^1S)10s	$^2P° - ^2S$ (14)	4946.5	49804.2	70014.7	6	2	0.10	0.012	1.2	-1.13	D	5
			4997.81	50011.2	70014.7	4	2	0.061	0.012	0.76	-1.34	D	5
			4847.14	49390.1	70014.7	2	2	0.041	0.014	0.46	-1.54	D	5
42	7p - (^1S)10d	$^2P° - ^2D$ (17)	4288.8	49804.2	73114.1	6	10	0.062	0.028	2.4	-0.77	D	5
			4325.73	50011.2	73122.2	4	6	0.059	0.025	1.4	-1.00	D	5
			4616.04	49390.1	73101.9	2	4	0.048	0.031	0.93	-1.21	D	5
			4329.62	50011.2	73101.9	4	4	0.0088	0.0025	0.14	-2.01	D	5
43	7p - (^1S)11s	$^2P° - ^2S$ (16)	4365.4	49804.2	72705.3	6	2	0.064	0.0061	0.52	-1.44	D	5
			4405.23	50011.2	72705.3	4	2	0.039	0.0057	0.33	-1.64	D	5
			4287.80	49390.1	72705.3	2	2	0.024	0.0068	0.19	-1.87	D	5
44	8p - (^1S)8d	$^2P° - ^2D$	19342	61536	66704.8	6	10	0.13	1.2	470	0.87	D	5
			[19643]	61636	66725.4	4	6	0.13	1.1	290	0.65	D	5
			[18729]	61336	66673.8	2	4	0.11	1.2	140	0.37	D	5
			[19845]	61636	66673.8	4	4	0.022	0.13	34	-0.28	D	5
45	8p - (^1S)9d	$^2P° - ^2D$	10982	61536	70639.3	6	10	0.063	0.19	41	0.05	D	5
			[11089]	61636	70651.9	4	6	0.063	0.17	25	-0.16	D	5
			[10768]	61336	70620.4	2	4	0.053	0.19	13	-0.43	D	5
			[11127]	61636	70620.4	4	4	0.010	0.019	2.7	-1.13	D	5

No.	Transition Array	Multiplet	λ(Å)	E_i(cm^{-1})	E_k(cm^{-1})	g_i	g_k	A_{ki}(10^8s^{-1})	f_{ik}	S(at.u.)	log gf	Accu.	L
46	8p - (^{1}S)10s	^{2}P° - ^{2}S	11791	61536	70014.7	6	2	0.069	0.048	11	-0.54	D	5
			[11932]	61636	70014.7	4	2	0.045	0.048	7.6	-0.71	D	5
			[11519]	61336	70014.7	2	2	0.024	0.048	3.6	-1.02	D	5
47	8p - (^{1}S)10d	^{2}P° - ^{2}D	8634.6	61536	73114.1	6	10	0.037	0.069	12	-0.38	D	5
			[8703.7]	61636	73122.2	4	6	0.037	0.063	7.3	-0.60	D	5
			[8496.8]	61336	73101.9	2	4	0.031	0.067	3.7	-0.88	D	5
			[8719.1]	61636	73101.9	4	4	0.0057	0.0066	0.75	-1.58	D	5
48	8p - (^{1}S)11s	^{2}P - ^{2}S	8950.6	61536	72705.3	6	2	0.041	0.016	2.9	-1.01	D	5
			[9031.5]	61636	72705.3	4	2	0.027	0.016	1.9	-1.19	D	5
			[8793.2]	61336	72705.3	2	2	0.014	0.016	0.95	-1.48	D	5

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