Calculated Line Strengths for the Transition Array (3d³ + 3d² 4s)– 3d² 4p in Ti II

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The transition array for the transitions between the configurations $(3d^3 + 3d^2 4s)$ and $3d^2 4p$ in Ti II are presented here. The relative line strengths have been calculated in the intermediate coupling scheme, taking into account interaction between configurations. The relative phase and magnitude of the radial transition integrals $(s–p)$ and $(d–p)$ for the jumping electron in the LS coupling have been determined empirically.

Key Words: Calculated line strengths; configuration interaction; intermediate coupling; Ti II; $3d^3$, $3d^2 4s$, $3d^2 4p$ configurations; transition array.

The line strengths for transitions between levels A and B are defined as in Condon and Shortley [1] as

$$\mathfrak{S}(A, B) = \sum_{a, b} |(a | \mathbf{P} | b)|^2, \qquad (1)$$

where the sum is over all the states which are the sublevels of the levels A and B. In this note, we first calculated the square roots of the relative strengths of the transitions between two given configurations in the LS representation and then transformed to the physical representation. It is assumed that the dipole approximation is valid. In this approximation the transition operator $\mathbf{P}$ is given by

$$\mathbf{P} = -\sum_j e\mathbf{r}_j \qquad (2)$$

where the sum is taken over all the electrons involved in the transition. The matrix elements for the transition can be readily calculated except for a radial integral factor common to all the matrix elements of the transition array [2, 3].

The radial integral depends upon the quantum numbers of the jumping electron in the upper and lower levels of the transition. In cases where the interaction between configurations is negligible, one has only one radial integral to consider in the LS representation. Therefore, upon transforming to the intermediate coupling scheme, the relative transition strengths are easily obtained. However, in the case of Ti II, the interaction between the configurations is important, so one has to consider more than one radial integral for the jumping electron. In Ti II, transitions between the following configurations may be important:

(1) $3d^3 - 3d^2 4p$,

(2) $3d^2 4s - 3d^2 4p$.

The state $|a)$ may then be expressed as a superposition of the eigenstates $|K)$ of the various configurations. Thus,

$$|a) = \sum_K |K)(K|a), \qquad (3)$$

where we have summed over the configurations K, and $(K|a)$ is the set of expansion coefficients. The matrix element of the transition between states a and b can be written as

$$(b|\mathbf{P}|a) = \sum_K \sum_{K'} (b|K')(K'|\mathbf{P}|K)(K|a), \qquad (4)$$

where $(K'|\mathbf{P}|K)$ are the matrix elements of the transition operator $\mathbf{P}$ expressed in the representation where the configurations K' and K are good quantum

numbers. In Ti II, this refers to the transition array in the LS representation for each configuration of the lower state separately. The matrix element for the transition can then be expressed as

$$(b|\mathbf{P}|a) = \sum_{\substack{\alpha \\ \beta}} (a|3d^2 4p, \beta)(3d^2 4p\beta|\mathbf{P}|3d^3, \alpha)(3d^3, \alpha|a)$$

$$+ \sum_{\substack{\alpha' \\ \beta'}} (b|3d^2 4p\beta')(3d^2 4p\beta'|\mathbf{P}|3d^2 4s\alpha')$$

$$(3d^2 4s, \alpha'|a) \qquad (5)$$

where α, α' and β, β' are the sets of relevant quantum numbers in the LS representation. In each of the two sums in eq (5) there is a factorable radial integral factor $(nl\|P\|n'l')$, where nl and $n'l'$ are the radial and orbital angular momentum quantum numbers of the jumping electron. Each set of configurations has a different set of n, l; n', l'. It is the phase and magnitude of the ratio of these radial factors which must be determined to calculate the relative intensities.

The determination of the expansion coefficients $(K|a)$ and the relative phase and magnitude as well

as comparison with experiments are discussed elsewhere [4]. In the table we show the strengths for the transition array for $3d^3 + 3d^2 4s - 3d^2 4p$ for Ti II. The composition of the upper and lower level is described in terms of the dominant states in the LS representation. For each position in the array, the upper number is the relative strength of the transition. The next lower number is the wavelength corresponding to the transition obtained from Russell's classifications [5], whenever available. The lowest number gives the wavenumber corresponding to the transition. The relative strengths are given to three significant figures for the stronger transitions and only one significant figure for the weaker lines. The number of significant figures given is consistent with the results of the diagonalization of the energy matrix and the empirical determination of the ratio of the radial integral parameters [4]. The magnitudes of the radial integral parameters have been found to be equal within the approximations that have been used, so in this table, the magnitudes of the radial integral factor have been taken to be unity for simplicity. Those relative strengths listed as zero indicate that, on the scale employed here, these strengths are less than 5×10^{-5}.

TABLE 1. *Transition array for* $(3d^3 + 3d^2 4s) - 3d^2 4p$ *in* Ti II *in intermediate coupling scheme with configuration interaction.*

The upper and lower levels are described in terms of the dominant states in the LS representation and the energy levels assigned in AEL [6]. For each position in the array, the upper number is the relative strength of the transition with the normalization of the radial integral parameter for the jumping electron in the d-p transition taken as unity. The next lower number is the wavelength corresponding to the transition obtained from Russell's classification when available. The lowest number is the wave number of the transition.

$(3d^3 + 3d^2 4s)$

1/2 1/2	a^2P 9850.90	a^4P 9363.71	a^2S 21338.0	b^2P 16515.79	b^4P 9872.87
z^2S° 37430.55	0.0004 3624.82 27579.65	0.0000 3561.92 28066.84	0.0000 6212.29 16092.55	0.30 4779.95 20914.76	0.0001 3627.70 27557.68
^{2}P° (63210.1)	0.0003 53359.20	0.0000 53846.39	0.66 41872.10	0.003 46694.31	0.0000 53337.23
y^2P° 45472.89	0.21 2806.50 35621.99	0.02 36109.18	0.004 24134.89	0.23 3452.47 28957.10	0.003 35600.02
z^2P° 39674.64	0.06 3352.06 29823.74	0.003 3298.20 30310.93	0.005 5452.02 18336.64	0.02 4316.80 23158.85	0.002 29801.77
z^4P° 41996.74	0.003 32145.84	0.01 3063.48 32633.03	0.0000 4839.22 20658.74	0.0001 25480.95	0.10 3112.05 32123.87
y^4D° 40330.25	0.005 30479.35	0.01 30966.54	0.0000 18992.25	0.0000 23814.46	0.55 3282.33 30457.38
z^4D° 32532.38	0.007 4407.68 22681.48	0.08 4314.98 23168.67	0.0000 11194.38	0.0000 16016.59	0.008 4411.94 22659.51

$(3d^2 4p)$

52

TABLE 1. — Continued

$$(3d^3 + 3d^2 4s)$$

(3d²4p)

3/2 1/2	a^2P 9975.92	a^4P 9395.76	d_1^2D (32358.5)	b_3^2D 12628.77	b^4F 907.96	b^2P 16625.25	b^4P 9930.74	a^2D 8710.47	a^4F 0	D²D 24961.34
$z^2S°$ 37430.55	0.26 3641.33 27454.63	0.04 3566.00 28034.79	0.0000 5072.05	0.002 24801.78	0.0000 36522.59	0.18 4805.10 20805.30	0.03 27499.81	0.02 3480.89 28720.08	0.0000 37430.55	0.0001 12469.21
$^2P°$ (63210.1)	0.0008 53234.18	0.0001 53814.34	0.14 30851.60	0.03 50581.33	0.0000 62302.14	0.002 46584.85	0.0001 53279.36	0.0002 54499.63	0.0000 63210.10	0.02 38248.76
$y^2P°$ 45472.89	0.01 35496.97	0.002 36077.13	0.14 13114.39	0.06 3043.85 32844.12	0.0000 44564.93	0.22 3465.58 28847.64	0.002 35542.15	0.001 2719.39 36762.42	0.0000 45472.89	0.04 4873.95 20511.55
$z^2P°$ 39674.64	0.09 3366.17 29698.72	0.02 30278.88	0.0008 7316.14	0.002 3696.38 27045.87	0.0001 38766.68	0.002 4337.32 23049.39	0.01 29743.90	0.69 3228.60 30964.17	0.0003 39674.64	0.008 14713.30
$z^4P°$ 41996.74	0.02 3122.10 32020.82	0.07 3066.52 32600.98	0.0000 9638.24	0.0001 29367.97	0.0000 41088.78	0.0001 25371.49	0.54 3117.67 32066.00	0.0000 33286.27	0.0000 41996.74	0.0000 17035.40
$y^4D°$ 40330.25	0.01 30354.33	0.002 30934.49	0.0000 7971.75	0.0000 27701.48	0.08 2535.87 39422.29	0.0001 23705.00	0.09 3288.58 30399.51	0.0008 31619.78	0.01 2478.77 40330.25	0.0000 15368.91
$z^4D°$ 32532.38	0.0005 4432.10 22556.46	0.02 4320.95 23136.62	0.0000 173.88	0.0000 19903.61	0.16 3161.20 31624.42	0.0000 15907.13	0.002 22601.64	0.0000 23821.91	0.66 3072.97 32532.38	0.0000 7571.04

TABLE 1.—Continued

$$(3d^3 + 3d^2 4s)$$

1/2 3/2	a^2P 9850.90	a^4P 9363.71	a^2S 21338.0	b^2P 16515.79	b^4P 9872.87
$z^4S°$ 40027.28	0.03 30176.38	0.09 3260.26 30663.57	0.0005 18689.28	0.0006 23511.49	0.20 3315.32 30154.41
$^2P°$ (63284.3)	0.0006 53433.40	0.0000 53920.59	1.32 41946.30	0.0007 46768.51	0.0000 53411.43
$y^2P°$ 45548.90	0.007 35698.00	0.0006 36185.19	0.007 24210.90	0.14 3443.38 29033.11	0.0000 35676.03
$z^2P°$ 39602.90	0.04 29752.00	0.02 3306.04 30239.19	0.01 5473.52 18264.90	0.002 4330.25 23087.11	0.01 3362.66 29730.03
$z^4P°$ 42068.85	0.0008 3103.00 32217.95	0.07 3056.74 32705.14	0.0001 20730.85	0.0001 25553.06	0.52 3105.08 32195.98
$x^2D°$ 44914.80	0.13 2851.10 35063.90	0.01 2812.05 35551.09	0.0001 23576.80	0.86 3520.25 28399.01	0.001 35041.93
$y^2D°$ 39233.44	0.05 3402.42 29382.54	0.004 29869.73	0.0003 17895.44	0.05 22717.65	0.008 3404.99 29360.57
$z^2D°$ 31756.50	0.18 4563.77 21905.60	0.03 4464.47 22392.79	0.0000 10418.50	0.01 6559.58 15240.71	0.0004 4568.30 21883.63
$y^4D°$ 40425.80	0.02 3269.75 30574.90	0.005 31062.09	0.0000 19087.80	0.001 23910.01	0.56 3272.08 30552.93
$z^4D°$ 32602.51	0.03 4394.06 22751.61	0.06 4301.93 23238.80	0.0000 11264.51	0.0006 16086.72	0.01 4398.31 22729.64
$z^4F°$ 30836.52	0.0003 20985.62	0.0000 21472.81	0.0000 9498.52	0.0000 14320.73	0.0000 20963.65

$(3d^2 4p)$

TABLE 1.—Continued

$$(3d^3 + 3d^24s)$$

3/2 3/2	a^2P 9975.92	a^4P 9395.76	d^2_1D (32358.5)	b^2_3D 12628.77	b^4F 907.96	b^2P 16625.25	b^4P 9930.74	a^2D 8710.47	a^4F 0	C^2D 24961.34
z^4S° 40027.28	0.0004 30051.36	0.18 3263.68 30631.52	0.0002 7668.78	0.005 27398.51	0.0000 39119.32	0.007 23402.03	0.52 3321.70 30096.54	0.009 3192.26 31316.81	0.0000 40027.28	0.0000 15065.94
^{2}P° (63284.3)	0.0003 53308.38	0.0000 53888.54	0.03 30925.80	0.003 50655.53	0.0000 62376.34	0.008 46659.05	0.0000 53353.56	0.004 54573.83	0.0000 63284.3	0.004 38322.96
y^2P° 45548.90	0.50 35572.98	0.06 2765.22 36153.14	0.04 13190.40	0.02 3036.78 32920.13	0.0000 44640.94	0.63 3456.39 28923.65	0.08 35618.16	0.001 2713.76 36838.43	0.0000 45548.90	0.01 20587.56
z^2P° 39602.90	0.12 3374.35 29626.98	0.05 30207.14	0.0001 7244.40	0.07 3706.23 26974.13	0.0000 38694.94	0.06 4350.83 22977.65	0.002 3369.20 29672.16	0.002 3236.12 30892.43	0.0001 39602.90	0.0000 14641.56
z^4P° 42068.85	0.04 3115.09 32092.93	0.02 3059.74 32673.09	0.0000 9710.35	0.0001 29440.08	0.0000 41160.89	0.0002 25443.60	0.14 3110.67 32138.11	0.0000 33358.38	0.0000 42068.85	0.0000 17107.51
x^2D° 44914.80	0.03 2861.29 34938.88	0.007 2814.61 35519.04	0.06 12556.30	0.0005 3096.43 32286.03	0.0000 44006.84	0.07 3533.85 28289.55	0.008 34984.06	0.16 2761.29 36204.33	0.0000 44914.80	0.02 5010.21 19953.46
y^2D° 39233.44	0.03 3416.95 29257.52	0.02 3350.53 29837.68	0.02 6874.94	0.008 3757.69 26604.67	0.0008 38325.48	0.04 4421.95 22608.19	0.01 29302.70	1.19 3275.38 30522.97	0.0000 39233.44	0.004 14272.10
z^2D° 31756.50	0.002 4589.95 21780.58	0.01 4470.88 22360.74	0.01	0.18 5226.56 19127.73	0.001 3240.72 30848.54	0.04 15131.25	0.001 4580.46 21825.76	0.002 4337.92 23046.03	0.03 3148.04 31756.50	0.0004 6795.16
y^4D° 40425.80	0.07 30449.88	0.009 31030.04	0.0008 8067.30	0.0001 3596.55 27797.03	0.03 2529.86 39517.84	0.001 23800.55	0.57 3278.29 30495.06	0.02 31715.33	0.004 40425.80	0.0001 15464.46
z^4D° 32602.51	0.02 4418.33 22626.59	0.09 4307.90 23206.75	0.0008 244.01	0.009 19973.74	0.07 3154.20 31694.55	0.002 15977.26	0.004 4409.53 22671.77	0.0001 4184.33 23892.04	0.23 3066.36 32602.51	0.0000 7641.17
z^4F° 30836.52	0.0000 20860.60	0.0000 21440.76	0.0001	0.0003 18207.75	0.32 3340.34 29928.56	0.0001 14211.27	0.0000 20905.78	0.0000 22126.05	1.07 3241.99 30836.52	0.0000 5875.18

$(3d^24p)$

55

Table 1.—Continued

$$(3d^3 + 3d^2 4s)$$

3/2 5/2	a^2P 9975.92	a^4P 9395.76	d_1^2D (32358.5)	b_3^3D 12628.77	b^4F 907.96	b^2P 16625.25	b^4P 9930.74	a^2D 8710.47	a^4F 0	C^2D 24961.34
$z^4P°$ 42208.84	0.02 32232.92	0.07 3046.69 32813.08	0.0000 9850.34	0.001 29580.07	0.0000 41300.88	0.001 25583.59	0.55 3097.19 32278.10	0.0000 33498.37	0.0000 42208.84	0.0000 17247.50
$x^2D°$ 44902.42	0.19 2862.32 34926.50	0.02 2815.57 35506.66	0.01 12543.92	0.02 3097.63 32273.65	0.0000 43994.46	1.39 3535.41 28277.17	0.03 34971.68	0.02 2762.22 36191.95	0.0000 44902.42	0.002 19941.08
$y^2D°$ 39476.87	0.07 3388.76 29500.95	0.04 30081.11	0.001 7118.37	0.10 3723.60 26848.10	0.0001 38568.91	0.07 4374.82 22851.62	0.10 29546.13	0.11 3249.37 30766.40	0.0000 39476.87	0.002 14515.53
$z^2D°$ 32025.50	0.24 4533.97 22049.58	0.13 4417.72 22629.74	0.004	0.02 5154.07 19396.73	0.0003 31117.54	0.02 6491.68 15400.25	0.02 4524.72 22094.76	0.006 4287.88 23315.03	0.003 3121.60 32025.50	0.0000 7064.16
$y^4D°$ 40581.80	0.28 3266.41 30605.88	0.005 31186.04	0.0000 8223.30	0.0000 3576.37 27953.03	0.002 2519.79 39673.84	0.004 23956.55	1.11 3261.59 30651.06	0.0000 3136.75 31871.33	0.0003 40581.80	0.0000 15620.46
$z^4D°$ 32697.94	0.08 4399.77 22722.02	0.12 4290.23 23302.18	0.0003 339.44	0.002 20069.17	0.005 31789.98	0.003 16072.69	0.06 4391.02 22767.20	0.0004 23987.47	0.01 3057.40 32697.94	0.0000 7736.60
$y^2F°$ 39926.83	0.01 3337.79 29950.91	0.005 30531.07	0.003 7568.33	0.23 3662.24 27298.06	0.0001 39018.87	0.001 23301.58	0.001 29996.09	1.35 3202.54 31216.36	0.0000 39926.83	0.02 6680.26 14965.49
$z^2F°$ 31207.44	0.002 4708.65 21231.52	0.0001 4583.44 21811.68	0.02	0.02 5381.02 18578.67	0.005 30299.48	0.0005 14582.19	0.0000 21276.70	0.21 4443.80 22496.97	0.0000 3203.44 31207.44	0.0001 6246.10
$x^2F°$ 47625.17	0.0003 2655.30 37649.25	0.0002 38229.41	0.20 15266.67	0.03 2856.62 34996.40	0.0000 46717.21	0.0006 30999.92	0.0001 37694.43	0.009 2568.98 38914.70	0.0000 47625.17	0.04 4411.08 22663.83
$z^4F°$ 30958.70	0.0001 20982.78	0.0000 4636.34 21562.94	0.0007	0.001 18329.93	0.08 3326.76 30050.74	0.0000 14333.45	0.0001 21027.96	0.007 4493.52 22248.23	0.26 3229.19 30958.70	0.0000 5997.36
$z^4G°$ 29544.37	0.0000 19568.45	0.0000 20148.61	0.0001	0.0000 16915.60	0.06 3491.05 28636.41	0.0000 12919.12	0.0000 19613.63	0.001 4798.52 20833.90	1.72 3383.76 29544.37	0.0000 4583.03

$(3d^2 4p)$

TABLE 1.—Continued

$$(3d^3 + 3d^24s)$$

(3d²4p)

5/2 3/2	a^4P 9518.05	d^2D (32362.7)	d_1^2D 12758.15	b^2F 20951.77	b^4F 983.80	b^4P 10024.74	a^2D 8744.27	a^2F 4628.61	a^4F 93.94	C^2D 25193.04
$z^4S°$ 40027.28	0.35 3276.76 30509.23	0.0000 7664.58	0.0000 27269.13	0.0000 19075.51	0.0001 39043.48	0.63 3332.11 30002.54	0.02 3195.71 31283.01	0.0002 35398.67	0.0000 39933.34	0.0008 14834.24
$^2P°$ (63284.3)	0.0000 53766.25	0.24 30921.60	0.06 50526.15	0.0000 42332.53	0.0000 62300.50	0.0000 53259.56	0.0001 54540.03	0.0000 58655.69	0.0000 63190.36	0.05 38091.26
$y^2P°$ 45548.90	0.0000 36030.85	0.23 13186.20	0.08 3048.77 32790.75	0.006 4064.40 24597.13	0.0000 44565.10	0.0000 35524.16	0.004 2716.25 36804.63	0.0003 40920.29	0.0000 45454.96	0.07 4911.19 20355.86
$z^2P°$ 39602.90	0.004 30084.85	0.0008 7240.20	0.008 3724.08 26844.75	0.0000 18651.13	0.0001 38619.10	0.007 3379.92 29578.16	1.41 3239.66 30858.63	0.003 2858.40 34974.29	0.0003 39508.96	0.02 14409.86
$z^4P°$ 42068.85	0.08 3071.24 32550.80	0.0000 9706.15	0.001 29310.70	0.0000 21117.08	0.0000 41085.05	0.64 3119.80 32044.11	0.0002 33324.58	0.0001 37440.24	0.0000 41974.91	0.0001 16875.81
$x^2D°$ 44914.80	0.0000 35396.75	0.02 12552.10	0.02 3108.93 32156.65	0.62 4171.90 23963.03	0.0000 43931.00	0.0001 34890.06	0.009 36170.53	0.04 2481.49 40286.19	0.0000 44820.86	0.004 5069.12 19721.76
$y^2D°$ 39233.44	0.003 29715.39	0.0007 6870.74	0.07 3776.06 26475.29	0.0004 18281.67	0.005 38249.64	0.0000 3422.69 29208.70	0.003 3278.92 30489.17	0.08 2888.93 34604.83	0.0005 39139.50	0.0000 14040.40
$z^2D°$ 31756.50	0.0004 22238.45	0.002	0.008 5262.14 18998.35	0.01 10804.73	0.01 30772.70	0.0003 21731.76	0.01 4344.29 23012.23	1.10 3685.19 27127.89	0.05 3157.39 31662.56	0.0000 6563.46
$y^4D°$ 40425.80	0.003 30907.75	0.0000 8063.10	0.003 27667.65	0.0000 19474.03	0.13 2534.62 39442.00	0.07 3288.42 30401.06	0.001 31681.53	0.002 35797.19	0.02 2478.64 40331.86	0.0000 15232.76
$z^4D°$ 32602.51	0.01 4330.71 23084.46	0.0001 239.81	0.0005 19844.36	0.0005 11650.74	0.23 3161.77 31618.71	0.0007 22577.77	0.001 4190.29 23858.24	0.06 3573.74 27973.90	1.01 3075.22 32508.57	0.0000 7409.47
$z^4F°$ 30836.52	0.0000 21318.47	0.0000	0.0001 18078.37	0.0000 9884.75	0.08 3348.82 29852.72	0.0000 20811.78	0.0000 22092.25	0.003 3814.57 26207.91	0.26 3251.91 30742.58	0.0000 5643.48

TABLE 1.—Continued

$$(3d^3 + 3d^2 4s)$$

5/2 5/2	a^4P 9518.05	d_1^2D (32362.7)	b_3^2D 12758.15	b^2F 20951.77	b^4F 983.80	b^4P 10024.74	a^2D 8744.27	a^2F 4628.61	a^4F 93.94	C^2D 25193.04
$z^4P°$ 42208.84	0.17 3058.09 32690.79	0.0004 9846.14	0.0006 29450.69	0.0000 21257.07	0.0000 41225.04	1.45 3106.23 32184.10	0.0002 2987.38 33464.57	0.0000 37580.23	0.0000 42114.90	0.0000 17015.80
$x^2D°$ 44902.42	0.0004 35384.37	0.10 12539.72	0.0009 3110.11 32144.27	0.04 23950.65	0.0000 43918.62	0.004 34877.68	0.26 2764.80 36158.15	0.009 40273.81	0.0000 44808.48	0.05 5072.30 19709.38
$y^2D°$ 39476.87	0.001 336.98 29958.82	0.03 7114.17	0.0000 3741.64 26718.72	0.0000 18525.10	0.002 38493.07	0.02 29452.13	1.72 30732.60	0.0001 2868.74 34848.26	0.0001 39382.93	0.006 14283.83
$z^2D°$ 32025.50	0.01 22507.45	0.02	0.22 5188.70 19267.35	0.0005 11073.73	0.007 3220.48 31041.70	0.0001 4544.01 22000.76	0.001 4294.12 23281.23	0.008 27396.89	0.06 3130.80 31931.56	0.0008 6832.46
$y^4D°$ 40581.80	0.01 31063.75	0.002 8219.10	0.001 3593.11 27823.65	0.0006 19630.03	0.04 2524.64 39598.00	0.53 3271.65 30557.06	0.07 31837.53	0.001 2780.55 35953.19	0.005 2469.15 40487.86	0.0003 15388.76
$z^4D°$ 32697.94	0.08 4312.87 23179.89	0.003 335.24	0.03 5013.69 19939.79	0.0000 11746.17	0.08 3152.25 31714.14	0.01 4409.23 22673.20	0.0002 4173.55 23953.67	0.008 3561.59 28069.33	0.27 3066.22 32604.00	0.0001 7504.90
$y^2F°$ 39926.83	0.0009 30408.78	0.004 7564.13	0.03 27168.68	0.08 5268.63 18975.06	0.0008 38943.03	0.002 29902.09	0.21 3206.00 31182.56	0.12 2832.16 35298.22	0.0001 39832.89	0.0002 14733.79
$z^2F°$ 31207.44	0.0002 21689.39	0.002	0.04 5418.77 18449.29	0.12 10255.67	0.02 3307.72 30223.64	0.0000 4719.51 21182.70	0.0008 4450.49 22463.17	1.70 3761.32 26578.83	0.05 3213.14 31113.50	0.0002 6014.40
$x^2F°$ 47625.17	0.0000 38107.12	0.02 15262.47	0.0001 34867.02	0.26 3748.01 26673.40	0.0000 46641.37	0.0001 37600.43	0.002 38880.90	0.01 42996.56	0.0000 47531.23	0.005 4456.62 22432.13
$z^4F°$ 30958.70	0.0000 21440.65	0.0000	0.0004 18200.55	0.005 10006.93	0.39 3335.20 29974.90	0.0000 20933.96	0.0001 22214.43	0.05 3796.88 26330.09	1.36 3239.04 30864.72	0.0000 5765.66
$z^4G°$ 29544.37	0.0000 20026.32	0.0000	0.0001 16786.22	0.0005 8592.60	0.01 3500.33 28560.57	0.0000 19519.63	0.0000 20800.10	0.008 4012.39 24915.76	0.26 3394.58 29450.43	0.0000 4351.33

$(3d^2 4p)$

TABLE 1.—Continued

$$(3d^3 + 3d^2 4s)$$

5/2 7/2	a^4P 9518.05	d^2D_1 (32362.7)	b^2D_3 12758.15	b^2F 20951.77	b^4F 983.80	b^4P 10024.74	a^2D 8744.27	a^2F 4628.61	a^4F 93.94	C^2D 25193.04
$y^4D°$ 40798.37	0.04 3195.99 31280.32	0.0002 8435.67	0.02 3565.33 28040.22	0.0000 19846.60	0.002 2510.90 39814.57	2.59 3248.60 30773.63	0.01 3118.85 32054.10	0.0002 2763.90 36169.76	0.0002 40704.43	0.001 15605.33
$z^4D°$ 32767.02	0.42 4300.05 23248.97	0.0000 404.32	0.0005 20008.87	0.0000 11815.25	0.004 31783.22	0.04 4395.86 22742.28	0.001 4161.54 24022.75	0.0002 28138.41	0.01 3059.73 32673.08	0.0000 7573.98
$y^2F°$ 40074.71	0.0005 30556.66	0.005 7712.01	0.33 3659.76 27316.56	0.002 19122.94	0.0001 39090.91	0.03 30049.97	2.07 3190.87 31330.44	0.008 35446.10	0.0001 39980.77	0.03 6717.89 14881.67
$z^2F°$ 31490.82	0.0002 21972.77	0.03	0.04 5336.81 18732.67	0.0003 10539.05	0.004 3276.98 30507.02	0.004 4657.20 21466.08	0.33 4395.04 22746.55	0.08 3721.64 26862.21	0.0004 3184.09 31396.88	0.0001 6297.78
$x^2F°$ 47466.80	0.0002 37948.75	0.28 15104.10	0.05 2880.28 34708.65	0.01 3770.40 26515.03	0.0000 46483.00	0.0002 37442.06	0.01 2581.73 38722.53	0.0000 42838.19	0.0000 47372.86	0.06 4488.32 22273.76
$z^4F°$ 31113.61	0.0002 21595.56	0.0007	0.001 18355.46	0.0000 10161.84	0.11 3318.03 30129.81	0.0002 21088.87	0.007 4469.15 22369.34	0.004 26485.00	0.33 3222.84 31019.67	0.0000 5920.57
$z^2G°$ 34543.36	0.0000 25025.31	0.0000 2180.66	0.0001 21785.21	0.03 13591.59	0.0000 33559.56	0.0000 24518.62	0.0000 25799.09	2.45 3341.88 29914.75	0.0001 2901.94 34449.42	0.0000 9350.32
$y^2G°$ 43740.77	0.0000 34222.72	0.0000 11378.07	0.0002 30982.62	0.20 4386.86 22789.00	0.0000 42756.97	0.0000 33716.03	0.0009 34996.50	0.07 2555.99 39112.16	0.0000 43646.83	0.0000 18547.73
$z^4G°$ 29734.45	0.0000 20216.40	0.0000	0.0000 16976.30	0.0000 8782.68	0.07 3477.18 28750.65	0.0000 19709.71	0.0006 4762.78 20990.18	0.0002 3982.01 25105.84	2.32 3372.80 29640.51	0.0000 4541.41

$(3d^2 4p)$

Table 1.—Continued

$(3d^3 + 3d^2 4s)$

7/2 5/2	b^2F 20891.88	b^4F 1087.21	a^2G 8997.69	a^2F 4897.60	a^4F 225.47	b^2G 15265.60
z^4P° 42208.84	0.0000 21316.96	0.0001 41121.63	0.0000 33211.15	0.0007 37311.24	0.0000 41983.37	0.0000 26943.24
x^2D° 44902.42	0.89 4163.65 24010.54	0.0000 43815.21	0.0004 35904.73	0.07 2498.94 40004.82	0.0000 44676.95	0.0007 29636.82
y^2D° 39476.87	0.003 18584.99	0.01 2604.11 38389.66	0.009 3279.98 30479.18	0.11 2891.07 34579.27	0.001 2546.88 39251.40	0.002 24211.27
z^2D° 32025.50	0.01 11133.62	0.05 3231.32 30938.29	0.005 4341.39 23027.81	1.52 3685.20 27127.90	0.19 3143.76 31800.03	0.0000 16759.90
y^4D° 40581.80	0.0000 19689.92	0.19 2531.25 39494.59	0.004 31584.11	0.004 35684.20	0.02 2477.21 40356.33	0.0007 25316.20
z^4D° 32697.94	0.002 11806.06	0.33 3162.57 31610.73	0.0001 23700.25	0.21 3596.05 27800.34	1.44 3078.64 32472.47	0.0000 17432.34
y^2F° 39926.83	0.004 19034.95	0.003 2573.91 38839.62	0.57 3232.28 30929.14	0.001 2853.93 35029.23	0.0005 2518.06 39701.36	0.09 4053.84 24661.23
z^2F° 31207.44	0.001 10315.56	0.002 3319.08 30120.23	0.23 4501.27 22209.75	0.02 3799.78 26309.84	0.02 3226.76 30981.97	0.0000 15941.84
x^2F° 47625.17	0.01 3739.50 26733.29	0.0000 46537.96	0.0000 38627.48	0.0000 42727.57	0.0000 47399.70	2.04 3089.40 32359.57
z^4F° 30958.70	0.0000 10066.82	0.11 3346.73 29871.49	0.009 21961.01	0.004 3836.10 26061.10	0.32 3252.91 30733.23	0.0000 15693.10
z^4G° 29544.37	0.0000 8652.49	0.0005 3513.08 28457.16	0.0006 4865.62 20546.68	0.0002 4056.20 24646.77	0.009 3409.81 29318.90	0.0000 14278.77

$(3d^2 4p)$

TABLE 1.—Continued

$(3d^3 + 3d^24s)$

$7/2$ / $7/2$	b^2F 20891.88	b^4F 1087.21	a^2G 8997.69	a^2F 4897.60	a^4F 225.47	b^2G 15265.60
$y^4D°$ 40798.37	0.003 19906.49	0.03 2517.43 39711.16	0.001 31800.68	0.005 2784.67 35900.77	0.004 2464.00 40572.90	0.0001 25532.77
$z^4D°$ 32767.02	0.0004 11875.14	0.07 3155.67 31679.81	0.0000 23769.33	0.006 3587.13 27869.42	0.24 3072.11 32451.55	0.0000 17501.42
$y^2F°$ 40074.71	0.10 5211.58 19182.83	0.002 38987.50	0.03 31077.02	0.17 2841.94 35177.11	0.0002 39849.24	0.002 24809.11
$z^2F°$ 31490.82	0.17 10598.94	0.02 3288.13 30403.61	0.007 4444.56 22493.13	2.21 3759.30 26593.22	0.04 3197.52 31265.35	0.001 16225.22
$x^2F°$ 47466.80	0.36 3761.89 26574.92	0.0000 46379.59	0.01 38469.11	0.01 42569.20	0.0000 47241.33	0.08 3104.60 32201.20
$z^4F°$ 31113.61	0.005 10221.73	0.58 3329.46 30026.40	0.0001 22115.92	0.05 3813.39 26216.01	2.04 3236.57 30888.14	0.0000 15848.01
$z^2G°$ 34543.36	0.0004 13651.48	0.0001 33456.15	0.31 3913.46 25545.67	0.09 3372.21 29645.76	0.0005 2913.08 34317.89	0.18 5185.90 19277.76
$y^2G°$ 43740.77	0.003 22848.89	0.0000 42653.56	0.008 2877.44 34743.08	0.005 2573.72 38843.17	0.0000 43515.30	2.63 3510.84 28475.17
$z^4G°$ 29734.45	0.0002 8842.57	0.02 3489.74 28647.24	0.0001 20736.76	0.003 4025.14 24836.85	0.33 3387.84 29508.98	0.0000 14468.85

$(3d^24p)$

TABLE 1.—Continued

$$(3d^3 + 3d^2 4s)$$

9/2, 11/2　　　7/2	b^2F 20891.88	b^4F 1087.21	a^2G 8997.69	a^2F 4897.60	a^4F 225.47	b^2G 15265.60
z^4F° 31300.92	0.0000 10409.04	0.09 3308.81 30213.71	0.0000 22303.23	0.002 26403.32	0.24 3217.06 31075.45	0.0000 16035.32
z^2G° 34748.50	0.04 13856.62	0.0000 33661.29	0.01 25750.81	3.16 3349.04 29850.90	0.0001 2895.81 34523.03	0.0007 19482.90
y^2G° 43780.99	0.25 4367.66 22889.11	0.0000 42693.78	0.01 2874.08 34783.30	0.10 2571.03 38883.39	0.0000 43555.52	0.05 3505.91 28515.39
z^4G° 29968.08	0.0000 9076.20	0.10 3461.50 28880.87	0.0000 20970.39	0.0000 25070.48	3.09 3361.21 29742.61	0.0000 14702.48
z^2H° 45673.75	0.0001 24781.87	0.0000 44586.54	0.02 2725.78 36676.06	0.0000 40776.15	0.0000 45448.28	3.30 3287.66 30408.15

$(3d^2 4p)$

62

TABLE 1.—Continued

$$(3d^3 + 3d^2 4s)$$

9/2, 11/2 / 7/2	b^4F 1215.58	a^2G 9118.15	a^2H 12676.99	a^4F 393.22	b^2G 15257.53
y^4D° 40798.37	0.28 2525.60 39582.79	0.03 31680.22	0.0000 28121.38	0.04 2474.22 40405.15	0.006 25540.84
z^4D° 32767.02	0.56 3168.52 31551.44	0.0007 23648.87	0.0000 20090.03	2.36 3088.02 32373.80	0.0000 17509.49
y^2F° 40074.71	0.01 38859.13	0.70 3229.42 30956.56	0.002 3648.87 27397.72	0.003 2519.31 39681.49	0.12 4028.34 24817.18
z^2F° 31490.82	0.0001 3302.09 30275.24	0.30 4468.50 22372.67	0.0001 18813.83	0.02 3214.75 31097.60	0.0000 16233.29
x^2F° 47466.80	0.0000 46251.22	0.0000 38348.65	0.0001 34789.81	0.0000 47073.58	2.63 3103.80 32209.27
z^4F° 31113.61	0.09 3343.77 29898.03	0.009 4545.14 21995.46	0.0001 18436.62	0.24 3254.25 30720.39	0.0000 15856.08
z^2G° 34543.36	0.0000 33327.78	0.03 3932.02 25425.21	0.66 4571.98 21866.37	0.0000 34150.14	0.001 5183.73 19285.83
y^2G° 43740.77	0.0000 42525.19	0.01 2887.46 34622.62	0.90 3218.27 31063.78	0.0000 43347.55	0.06 3509.85 28483.24
z^4G° 29734.45	0.0005 28518,87	0.0002 20616.30	0.0003 17057.46	0.006 3407.20 29341.23	0.0000 14476.92

$(3d^2 4p)$

63

Table 1.—Concluded

$(3d^3 + 3d^24s)$

9/2, 11/2 \ 9/2, 11/2	b^4F 1215.58	a^2G 9118.15	a^2H 12676.99	a^4F 393.22	b^2G 15257.53	a^2H 12774.81
$z^4F°$ 31300.92	0.91 3322.94 30085.34	0.0001 22182.77	0.0000 18623.93	3.10 3234.52 30907.70	0.0004 16043.39	0.0001 18526.11
$z^2G°$ 34748.50	0.0005 33532.92	0.38 3900.54 25630.35	0.02 4529.46 22071.51	0.003 2909.92 34355.28	0.24 5129.15 19490.97	0.81 4549.63 21973.69
$y^2G°$ 43780.99	0.0000 42565.41	0.01 2884.11 34662.84	0.03 3214.12 31104.00	0.0000 43387.77	3.33 3504.89 28523.46	1.09 3224.24 31006.18
$z^4G°$ 29968.08	0.01 3476.99 28752.50	0.0000 20849.93	0.0000 17291.09	0.35 3380.28 29574.86	0.0000 14710.55	0.30 17193.27
$z^2H°$ 45673.75	0.0000 44458.17	0.004 36555.60	0.0000 3029.73 32996.76	0.0009 45280.53	0.05 3286.78 30416.22	0.009 3038.71 32898.94
$z^4G°$ 30240.68	0.13 3444.31 29025.10	0.0000 21122.53	0.0000 17563.69	4.00 3349.41 29847.46	0.0000 14983.15	0.0000 17465.87
$z^2H°$ 45908.56	0.0000 44692.98	0.02 2717.29 36790.41	0.01 3008.33 33231.57	0.0000 45515.34	4.02 3261.60 30651.03	0.47 3017.19 33133.75

$(3d^24p)$

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