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Investigation of the hyperfine structure of Ta I-lines (IV)

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Abstract. The hyperfine structure of about 200 lines of the neutral tantalum atom was investigated by means of Doppler limited laser spectroscopy. From the spectra we have deduced the magnetic hyperfine interaction constants A and the electric quadrupole interaction constants B of 8 levels with even parity and 81 levels with odd parity. Further, we have discovered 24 new levels of even parity and 11 new levels of odd parity.

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1 Introduction

This work continues the earlier laser spectroscopic hyperfine structure (hfs) investigation of Ta I lines [1–6] done by two groups in Hamburg and Graz. Besides this research work, many other authors [7–15] have carried out hfs investigation in the atomic spectrum of tantalum. For many of the well known atomic energy levels, listed in the tables of Moore [16] and Klinkenberg *et al.* [17,18], no hfs-data are available. In this work we will report the hyperfine interaction constants of energy levels from which we were able to determine the A- and B-values.

Another part of this work was the discovery of energy levels which were not previously known and the determination of their energy, total electronic angular momentum quantum number, parity and hyperfine interaction constants (Tabs. 6 and 7). The hyperfine investigation extended over the spectral region from 360 to 900 nm.

2 Experiment and data evaluation

The experimental arrangement has already been described in a former paper [4]. We have used a tantalum hollow cathode discharge where a proper density of tantalum atoms was produced by cathode sputtering with argon as the carrier gas.

By chopping the exciting, tunable laser beam we were able to use either the optogalvanic effect or the laser induced fluorescence (LIF) light intensity change detection. Spectral lines which were suited for LIF detection could be selected by a grating spectrometer. The hyperfine spectra were recorded *via* a lock-in-amplifier with digital data output.

The line shape of a single hyperfine component was modelled using a two parameter Voigt-profile. The hyperfine spectrum was calculated using the involved hyperfine constants, the intensities of the individual hyperfine components and their shape. The sum of all components correctly placed was adjusted to the measured structure *via* an iterative least squares fitting procedure. The shape parameters, the hyperfine interaction constants and the intensities (of the well resolved) hyperfine components were taken as free parameters of this least squares routine.

3 Results and discussion

The existence of unclassified spectral lines points to the possibility of not yet known levels. So, an important aim of our work was the classification of such lines, which we have picked up out of compendia like the MIT- or the NBS-tables [19,20]. We have carried out this either by direct excitation of the line or by observing the respective line as a transition showing LIF, *i.e.* a spontaneous decay of one of the levels the laser combines (see Tab. 2).

The investigated lines are listed in Tables 1 and 2. To be consistent with the commonly used wavelength tables all wavelengths in the tables of this paper are given as wavelengths in air in units of Ångstroem. In those columns where only the first four digits of a wavelength are given, we have truncated the wavelength entry after the decimal point.

We were able to excite Ta I transitions up to a lower level energy of 45 000 cm^{-1} with a remarkably good signal to noise ratio. Some of the hyperfine constants of the lower levels were known from the literature with high accuracy. In those cases we introduced these A- and B-factors keeping them fixed during the fitting procedure in order to determine the A- and B-values of the upper level more precisely.

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Table 1. Investigated lines of Ta I. The relative intensities of these lines were taken from [19,20]. Lines with no intensity numbers are calculated lines which are not listed in the above mentioned sources. Lines where the classification was already known are labelled superscripted *a*. λ_F is the observed fluorescence line of the transition. A superscripted *n* means that the observed fluorescence line is stemming from the lower level, depopulated by the laser. Fluorescence lines which were not spontaneous decays of the excited levels are labelled superscripted *c*. Nevertheless, in these cases a LIF-signal could be observed due to collisions in the plasma acting as a thermal bath. Lines where the difference between the vacuum wavenumbers, which are given in [20] or [19], and the calculated wavenumbers (difference of energies) exceeds 0.15 cm^{-1} are labelled superscripted *b*. Lines with a new center of gravity wavelength are labelled superscripted *f*.

	intensity in	transition		energy levels / cm^{-1}		
λ/Å	[20] ; [19]	des. even	des. odd	even	odd	λ_F/Å
3 633.760 ^{a,f}	55 ; 35	$a\ ^4\mathrm{P}_{1/2}$	$?_{1/2}$	6 049.42	33 561.28	2 978
4 322.684 ^{a}	65 ; 5	$a\ ^2\mathrm{F}_{7/2}$	$?_{5/2}$	17 383.12	40 510.45	6 262
4 403.29	– ; –	$^4\mathrm{G}_{7/2}$	$?_{9/2}$	24 917.90	47 621.88	3 101
4 833.259	– ; –	$^4\mathrm{G}_{9/2}$	$?_{9/2}$	25 376.41	46 060.60	2 749
4 852.684 ^{a}	– ; 10	$?_{3/2}$	$z\ ^4\mathrm{F}_{5/2}$	43 964.50	23 363.09	4 521
4 864.664 ^{a}	– ; 20	$^6\mathrm{G}_{3/2}$	$z\ ^2\mathrm{P}_{1/2}$	10 950.22	31 500.99	3 173
4 871.601	– ; –	$^4\mathrm{D}_{5/2}$	$?_{3/2}$	25 655.36	46 176.76	2 761
4 879.144 ^{a}	13 ; 25	$^4\mathrm{H}_{9/2}$	$?_{7/2}$	23 912.89	44 402.56	2 577
4 918.876	– ; 4	$^4\mathrm{F}_{3/2}$	$?_{3/2}$	22 842.84	43 167.07	2 694
4 924.561	– ; –	$^2\mathrm{D}_{3/2}$	$?_{3/2}$	25 876.05	46 176.76	2 761
4 953.128	– ; –	$^2\mathrm{I}_{11/2}$	$?_{11/2}$	29 498.60	49 682.23	2 915
5 030.571	– ; –	$^2\mathrm{G}_{7/2}$	$?_{9/2}$	29 276.39	49 149.30	2 599
5 115.843	110 ; 80	$e\ ^6\mathrm{F}_{11/2}$	$^6\mathrm{G}_{13/2}$	47 319.57	27 778.09	4 480
5 471.565 ^{b}	13 ; 2	$^4\mathrm{D}_{7/2}$	$?_{7/2}$	25 894.09	44 165.58	4 344
5 490.114	40 ; 60	$a\ ^4\mathrm{H}_{13/2}$	$^4\mathrm{I}_{15/2}$	23 514.86	41 724.35	2 845 ^{c}
5 491.312	– ; –	$^4\mathrm{F}_{5/2}$	$?_{7/2}$	24 546.20	42 751.72	3 025
5 513.507	– ; 2	$^4\mathrm{D}_{3/2}$	$?_{3/2}$	24 275.96	42 408.16	3 207
5 517.727	– ; 2	$a\ ^4\mathrm{D}_{7/2}$	$?_{7/2}$	26 575.02	44 693.40	2 857
5 523.982	– ; 2	$?_{5/2}$	$y\ ^4\mathrm{D}_{3/2}$	44 461.60	26 363.69	4 527
5 549.311	– ; 4	$^4\mathrm{G}_{9/2}$	$^2\mathrm{H}_{9/2}$	25 376.41	43 391.71	5 755
5 685.456	– ; 7	$^4\mathrm{D}_{5/2}$	$?_{5/2}$	25 655.36	43 239.22	4 424
5 724.406	– ; 2	$a\ ^4\mathrm{D}_{3/2}$	$?_{1/2}$	21 381.01	38 845.25	2 573
5 733.490	– ; 2	$a\ ^4\mathrm{G}_{5/2}$	$?\ _{5/2}$	21 622.92	39 059.52	2 698
5 746.532	– ; –	$a\ ^4\mathrm{H}_{13/2}$	$z\ ^4\mathrm{I}_{13/2}$	23 514.86	40 911.83	5 408
5 753.695	– ; –	$^4\mathrm{G}_{9/2}$	$?\ _{7/2}$	25 376.41	42 751.72	3 025
5 753.974	– ; –	$?\ _{3/2}$	$z\ ^4\mathrm{P}_{3/2}$	43 964.50	26 590.03	4 033
5 824.297	– ; –	$a\ ^4\mathrm{D}_{3/2}$	$?\ _{3/2}$	21 381.01	38 545.70	3 661
5 835.809	– ; –	$a\ ^4\mathrm{G}_{5/2}$	$?\ _{5/2}$	21 622.92	38 753.75	3 595
5 837.275	– ; 4	$a\ ^4\mathrm{D}_{3/2}$	$y\ ^6\mathrm{F}_{1/2}$	21 381.01	38 507.54	3 503
5 907.556	– ; –	$a\ ^4\mathrm{G}_{5/2}$	$?_{3/2}$	21 622.92	38 545.70	3 661
5 971.571	– ; –	$a\ ^2\mathrm{H}_{9/2}$	$?_{7/2}$	15 391.01	32 132.38	3 318
6 070.536	– ; 2	$^4\mathrm{D}_{3/2}$	$?_{5/2}$	27 412.36	43 880.84	3 159
6 092.065 ^{a}	18 ; 30	$^4\mathrm{F}_{3/2}$	$?_{3/2}$	22 842.84	39 253.07	2 684
6 218.99	– ; 5	$^4\mathrm{G}_{5/2}$	$y\ ^6\mathrm{F}_{3/2}$	23 512.34	39 587.81	3 351
6 222.694	– ; 2	$^4\mathrm{D}_{3/2}$	$y\ ^4\mathrm{P}_{1/2}$	27 412.36	43 478.20	3 073
6 223.612	– ; 2	$^4\mathrm{D}_{3/2}$	$?_{3/2}$	24 275.96	40 339.20	3 292
6 254.686	– ; 5	$a\ ^4\mathrm{F}_{5/2}$	$?_{5/2}$	2 010.10	17 993.74	7 125
6 266.371	– ; 50	$a\ ^4\mathrm{H}_{13/2}$	$z\ ^4\mathrm{I}_{11/2}$?	23 514.86	39 468.63	5 458

Table 1. *Continued.*

	intensity in	transition		energy levels / cm^{-1}		
λ/Å	[20] ; [19]	des. even	des. odd	even	odd	λ_F/Å
6 287.361[a]	15 ; 5	$a\ ^4G_{5/2}$	$?_{3/2}$	21 622.92	37 523.54	3 178
6 339.981	– ; 5	$^4G_{7/2}$	$y\ ^4G_{9/2}$	24 917.90	40 686.42	3 909
6 351.238	– ; 5	$^4G_{5/2}$	$?_{3/2}$	23 512.34	39 253.07	6 092
6 373.055 [a]	36 ; 50	$^4H_{7/2}$	$y\ ^4F_{5/2}$	22 761.21	38 447.99	3 674
6 421.973	– ; –	$^6S_{5/2}$	$?_{7/2}$	32 502.38	48 069.61	2 575
6 425.442	– ; 3	$^2I_{11/2}$	$?_{11/2}$	29 498.60	45 057.34	3 153
6 426.731	– ; 5	$^4H_{9/2}$	$?_{11/2}$	23 912.89	39 468.63	2 953
6 437.365	13 ; 2	$^2G_{7/2}$	$x\ ^6D_{7/2}$	30 879.72	46 409.79	2 842
6 443.887	– ; 10	$a\ ^4H_{11/2}$	$z\ ^4I_{9/2}$?	22 428.56	37 942.84	5 780
6 445.866 [a]	30 ; 20	$^4H_{9/2}$	$?_{9/2}$	23 912.89	39 422.40	2 957
6 459.065	– ; 2	$a\ ^4H_{9/2}$	$?_{9/2}$	21 153.33	36 631.15	3 060
6 472.855	– ; 2	$a\ ^4D_{3/2}$	$y\ ^4G_{5/2}$?	21 381.01	36 825.97	5 141
6 479.466	– ; –	$^2H_{9/2}$	$?_{9/2}$	32 192.70	47 621.80	2 706
6 479.601	– ; –	$^6S_{5/2}$	$?_{7/2}$	32 502.38	47 931.16	2 584
6 480.895	– ; –	$^6S_{5/2}$	$?_{5/2}$	32 502.38	47 928.08	2 615
6 500.40	– ; 2	$^4G_{9/2}$	$?_{7/2}$	25 376.41	40 755.90	3 584
6 714.44 [a]	10 ; 4	$a\ ^4G_{11/2}$	$z\ ^4I_{13/2}$	26 022.74	40 911.83	5 408
6 776.65	– ; 2	$?_{3/2}$	$?_{5/2}$	44 095.95	29 343.46	4 012
6 784.384	– ; –	$^2H_{11/2}$	$x\ ^6D_{9/2}$	33 064.15	47 799.81	2 902
6 811.189	– ; –	$^4D_{5/2}$	$?_{7/2}$	25 655.36	40 333.03	2 608
6 867.344	– ; –	$^2H_{11/2}$	$?_{9/2}$	33 064.15	47 621.80	2 706
6 890.539	– ; –	$^6S_{5/2}$	$?_{5/2}$	32 502.38	17 993.74	4 302 [c]
6 892.40 [b]	– ; 30	$^4G_{7/2}$	$?_{9/2}$	24 917.90	39 422.40	2 957
6 896.806	– ; –	$a\ ^4D_{3/2}$	$?_{5/2}$	21 381.01	35 876.47	2 951
6 896.958	– ; –	$?_{5/2}$	$y\ ^6D_{5/2}$	46 981.89	32 486.75	4 336
6 899.138	– ; –	$^4D_{3/2}$	$?_{1/2}$	27 412.36	41 902.92	2 788
6 904.063	– ; –	$^2D_{5/2}$	$?_{5/2}$	32 916.84	47 397.06	2 895
6 910.435	– ; –	$^4D_{3/2}$	$?_{5/2}$	27 412.36	41 879.23	2 507
6 923.804	– ; –	$^4D_{7/2}$	$?_{7/2}$	25 894.09	40 333.03	2 608
6 925.237	– ; –	$^4D_{1/2}$	$?_{1/2}$	26 743.95	41 179.90	3 181
6 936.05	– ; 2	$^4F_{3/2}$	$?_{5/2}$	43 275.47	28 862.01	3 954
6 949.568	– ; –	$^6S_{5/2}$	$?_{3/2}$	32 502.38	46 887.79	4 055
6 950.08	– ; 2	$^4H_{7/2}$	$?_{5/2}$	22 761.21	37 145.60	2 691
6 953.990	– ; –	$^2G_{7/2}$	$x\ ^6D_{5/2}$	30 879.72	45 255.98	3 027
6 981.306	– ; –	$?_{7/2}$	$?_{9/2}$	47 817.16	33 497.15	4 566
7 005.90	– ; 2	$^4D_{3/2}$	$?_{3/2}$	24 275.96	38 545.70	3 661
7 013.94	– ; 2	$?_{3/2}$	$y\ ^6D_{5/2}$	46 740.13	32 486.75	3 909
7 023.005	– ; –	$^2G_{7/2}$	$?_{7/2}$	30 879.72	45 114.71	2 787
7 031.846	– ; –	$^2H_{9/2}$	$x\ ^6D_{7/2}$	32 192.70	46 409.79	2 842
7 036.60	– ; 2	$^4F_{5/2}$	$?_{5/2}$	24 546.20	38 753.75	3 595
7 049.86	– ; 3	$a\ ^4D_{7/2}$	$?_{7/2}$	26 575.02	40 755.90	2 845
7 074.68	– ; 3	$^4D_{5/2}$	$?_{5/2}$	25 655.36	39 786.52	2 646
7 085.300	– ; –	$a\ ^4D_{1/2}$	$?_{1/2}$	22 235.97	36 345.80	3 299
7 091.36 [b]	– ; 2	$a\ ^4G_{5/2}$	$^4F_{3/2}$	21 622.92	35 721.00	2 965

Table 1. *Continued.*

	intensity in	transition		energy levels / cm^{-1}		
λ/Å	[20] ; [19]	des. even	des. odd	even	odd	λ_{F}/Å
7 092.16	– ; 2	$^{2}\mathrm{D}_{5/2}$	$?_{7/2}$	32 916.84	47 013.02	2 752
7 092.16	– ; 2	$^{2}\mathrm{H}_{11/2}$	$?_{9/2}$	33 064.15	47 160.34	3 119
7 108.05 [a]	8 ; 3	$^{4}\mathrm{H}_{7/2}$	$y\ ^{4}\mathrm{G}_{5/2}$?	22 761.21	36 825.97	3 686
7 116.07	– ; 4	$^{4}\mathrm{G}_{5/2}$	$?_{7/2}$	23 512.34	37 561.25	2 975
7 118.09	– ; 2	$a\ ^{2}\mathrm{F}_{7/2}$	$?_{5/2}$	17 383.12	31 428.05	3 180
7 125.641	– ; –	$^{4}\mathrm{H}_{9/2}$	$z\ ^{4}\mathrm{I}_{9/2}$?	23 912.89	37 942.84	2 942
7 125.72 [a]	40 ; 80	$a\ ^{4}\mathrm{F}_{7/2}$	$?_{5/2}$	3 963.92	17 993.74	6 254
7 135.22	– ; 2	$^{4}\mathrm{G}_{5/2}$	$?_{3/2}$	23 512.34	37 523.54	3 176
7 188.427	– ; –	$^{6}\mathrm{S}_{5/2}$	$x\ ^{6}\mathrm{D}_{7/2}$	32 502.38	46 409.79	2 842
7 195.827	– ; –	$^{2}\mathrm{I}_{11/2}$	$?_{9/2}$	29 498.60	4 3391.71	5 755
7 196.24	– ; 3	$^{4}\mathrm{D}_{7/2}$	$?_{5/2}$	25 894.09	39 786.52	2 646
7 207.82	– ; 2	$^{4}\mathrm{H}_{7/2}$	$?_{9/2}$	22 761.21	36 631.15	3 223
7 233.45	8 ; 10	$^{6}\mathrm{S}_{5/2}$	$y\ ^{4}\mathrm{P}_{5/2}$	32 502.38	46 323.31	2 696
7 264.82 [a]	11 ; 10	$^{4}\mathrm{G}_{7/2}$	$y\ ^{4}\mathrm{G}_{7/2}$	24 917.90	38 679.05	3 571
7 272.29	6 ; 5	$^{4}\mathrm{D}_{7/2}$	$?_{7/2}$	25 894.09	39 641.24	2 802
7 296.32	13 ; 40	$a\ ^{4}\mathrm{H}_{11/2}$	$?_{13/2}$	22 428.56	36 130.32	3 311 [c]
7 313.18	– ; 3	$^{6}\mathrm{S}_{5/2}$	$?_{7/2}$	32 502.38	46 172.44	3 045
7 313.18	– ; 3	$a\ ^{2}\mathrm{F}_{5/2}$	$z\ ^{4}\mathrm{S}_{3/2}$	17 224.47	30 894.67	4 619
7 340.19 [a]	11 ; 10	$a\ ^{4}\mathrm{G}_{5/2}$	$?_{3/2}$	21 622.92	35 242.94	3 922
7 343.057	– ; –	$^{6}\mathrm{S}_{5/2}$	$?_{5/2}$	32 502.38	46 116.93	2 371
7 343.33	– ; 2	$^{2}\mathrm{D}_{3/2}$	$?_{1/2}$	25 876.05	39 490.14	3 502
7 346.41 [a]	160 ; 100	$a\ ^{4}\mathrm{P}_{1/2}$	$z\ ^{4}\mathrm{D}_{3/2}$	6 049.42	19 657.78	5 664
7 355.44	– ; 10	$^{2}\mathrm{I}_{11/2}$	$?_{9/2}$	29 498.60	43 090.28	3 361
7 356.96[a]	100 ; 100	$a\ ^{4}\mathrm{P}_{3/2}$	$z\ ^{4}\mathrm{D}_{3/2}$	6 068.91	19 657.78	5 664
7 389.868	– ; –	$^{4}\mathrm{D}_{7/2}$	$?_{9/2}$	25 894.09	39 422.40	6 445
7 404.93	– ; 3	$^{4}\mathrm{D}_{1/2}$	$?_{1/2}$	26 743.95	40 244.74	3 513
7 418.92	– ; 2	$^{2}\mathrm{G}_{7/2}$	$?_{7/2}$	29 276.39	42 751.72	3 025
7 435.19 [a]	11 ; 5	$a\ ^{4}\mathrm{G}_{11/2}$	$z\ ^{4}\mathrm{I}_{11/2}$?	26 022.74	39 468.63	2 953
7 454.35	– ; 5	$a\ ^{4}\mathrm{D}_{3/2}$	$?_{5/2}$	21 381.01	34 792.22	3 480
7 460.82	– ; 5	$a\ ^{4}\mathrm{G}_{11/2}$	$?_{9/2}$	26 022.74	39 422.40	2 957
7 469.08	– ; 5	$a\ ^{4}\mathrm{H}_{11/2}$	$?_{11/2}$	22 428.56	35 813.47	3 979
7 479.337	– ; –	$a\ ^{2}\mathrm{F}_{5/2}$	$?_{7/2}$	17 224.47	30 590.95	3 497
7 495.35	– ; 4	$a\ ^{4}\mathrm{G}_{11/2}$	$z\ ^{4}\mathrm{H}_{13/2}$	26 022.74	39 360.68	4 123
7 509.028	– ; –	$^{4}\mathrm{G}_{5/2}$	$y\ ^{4}\mathrm{G}_{5/2}$?	23 512.34	36 825.97	2 714
7 515.17	– ; 5	$^{4}\mathrm{G}_{9/2}$	$y\ ^{4}\mathrm{G}_{7/2}$	25 376.41	38 679.05	3 571
7 569.23 [a]	6 ; 3	$a\ ^{2}\mathrm{F}_{7/2}$	$?_{7/2}$	17 383.12	30 590.95	3 497
7 590.22 [a]	9 ; 8	$^{4}\mathrm{F}_{3/2}$	$z\ ^{4}\mathrm{G}_{5/2}$?	22 842.84	36 013.97	3 988
7 593.58	– ; 2	$^{4}\mathrm{D}_{7/2}$	$?_{5/2}$	25 894.09	39 059.52	3 030
7 604.81	– ; 2	$^{6}\mathrm{S}_{5/2}$	$?_{7/2}$	32 502.38	45 648.26	3 095
7 620.84	– ; 2	$^{2}\mathrm{D}_{3/2}$	$?_{3/2}$	25 876.05	38 994.33	4 329
7 622.64	– ; 2	$^{4}\mathrm{H}_{7/2}$	$?_{5/2}$	22 761.21	35 876.47	2 951
7 632.636	– ; –	$^{4}\mathrm{D}_{3/2}$	$?_{5/2}$	27 412.36	40 510.45	4 322
7 640.84	– ; 4	$^{4}\mathrm{F}_{5/2}$	$?_{5/2}$	24 546.20	37 630.09	2 806
7 670.28	– ; 15	$^{4}\mathrm{F}_{3/2}$	$?_{5/2}$	22 842.84	35 876.47	2 951

Table 1. *Continued.*

	intensity in	transition		energy levels / cm^{-1}		
λ/Å	[20] ; [19]	des. even	des. odd	even	odd	λ_F/Å
7 670.391	– ; –	?$_{5/2}$	?$_{5/2}$	44 461.60	31 428.05	3 180
7 676.20	– ; 3	$^4\mathrm{D}_{5/2}$	$y\ ^4\mathrm{G}_{7/2}$	25 655.36	38 679.05	3 571
7 699.14	– ; 5	$^4\mathrm{H}_{7/2}$	?$_{7/2}$	22 761.21	35 746.18	4 369
7 715.03 ^{a}	– ; 2	$^2\mathrm{P}_{3/2}$	?$_{5/2}$	15 903.77	28 862.01	3 463
7 719.16	– ; 3	$a\ ^6\mathrm{D}_{7/2}$	?$_{9/2}$	12 234.76	25 185.89	5 109
7 725.04	– ; 4	$a\ ^4\mathrm{H}_{9/2}$	$y\ ^6\mathrm{D}_{7/2}$	21 153.33	34 094.66	3 317
7 733.77	– ; 2	$^4\mathrm{D}_{3/2}$	?$_{3/2}$	27 412.36	40 339.20	4 091
7 758.23	– ; 2	$^2\mathrm{G}_{7/2}$	?$_{5/2}$	30 879.72	17 993.74	6 437
7 762.944	– ; –	$^4\mathrm{F}_{3/2}$	?$_{3/2}$	22 842.84	35 721.00	5 404
7 763.11 ^{b}	11 ; 25	$^2\mathrm{D}_{3/2}$	?$_{5/2}$	25 876.05	38 753.75	4 678
7 773.53	– ; 3	?$_{5/2}$	?$_{7/2}$	44 461.60	31 600.95	4 527
7 779.72 ^{a,b}	9 ; 30	$a\ ^4\mathrm{H}_{7/2}$	?$_{9/2}$	20 646.54	33 497.15	3 586
7 788.810 ^{f}	– ; 3	$a\ ^4\mathrm{D}_{1/2}$	?$_{1/2}$	22 235.97	35 071.36	2 850
7 799.51	– ; 3	$^4\mathrm{G}_{9/2}$	$z\ ^4\mathrm{H}_{11/2}$	25 376.41	38 194.22	6 341
7 806.234	– ; –	$^2\mathrm{D}_{5/2}$	?$_{3/2}$	32 916.84	45 723.58	2 741
7 814.03	– ; 50	$a\ ^4\mathrm{P}_{5/2}$	$z\ ^2\mathrm{D}_{5/2}$	9 253.43	22 047.45	6 256
7 815.48	– ; 25	$a\ ^2\mathrm{H}_{9/2}$	?$_{7/2}$	15 391.01	28 182.60	6 268
7 819.57	– ; 2	$^4\mathrm{D}_{7/2}$	$y\ ^4\mathrm{G}_{7/2}$	25 894.09	38 679.05	3 571
7 825.878	– ; –	$^2\mathrm{H}_{11/2}$	$y\ ^6\mathrm{F}_{11/2}$	33 064.15	45 838.75	2 844
7 844.767	– ; –	$^6\mathrm{S}_{5/2}$	$x\ ^6\mathrm{D}_{3/2}$	32 502.38	45 246.22	2 940
7 847.674	– ; –	?$_{7/2}$	?$_{7/2}$	50 992.51	38 253.39	3 029
7 869.540	– ; –	$^4\mathrm{F}_{5/2}$	$y\ ^6\mathrm{D}_{5/2}$	44 918.67	32 486.75	6 578
7 882.37 ^{a}	100 ; 150	$a\ ^6\mathrm{D}_{5/2}$	$z\ ^4\mathrm{D}_{7/2}$	11 243.63	23 926.68	6 813
7 889.827	– ; –	$^2\mathrm{G}_{7/2}$	?$_{5/2}$	30 879.72	43 550.78	2 406
7 919.527	– ; –	$^4\mathrm{D}_{5/2}$	?$_{3/2}$	27 715.66	40 339.20	2 478
7 923.400	– ; –	$^4\mathrm{D}_{5/2}$	?$_{7/2}$	27 715.66	40 333.03	2 608
7 924.600	– ; –	$a\ ^4\mathrm{H}_{13/2}$	?$_{13/2}$	23 514.86	36 130.32	3 311 ^{c}
7 925.552	– ; –	$^2\mathrm{H}_{9/2}$	$y\ ^6\mathrm{F}_{9/2}$	32 192.70	44 806.64	3 069
7 937.496	– ; –	?$_{3/2}$	$z\ ^2\mathrm{P}_{1/2}$	44 095.95	31 500.99	4 494
7 952.07	5 ; 3	$^2\mathrm{D}_{3/2}$	$y\ ^4\mathrm{F}_{5/2}$	25 876.05	38 447.99	4 745
7 973.905	– ; –	$^4\mathrm{F}_{3/2}$	?$_{1/2}$	43 275.47	55 812.93	4 232 ^{n}
7 981.384	– ; –	$^2\mathrm{H}_{9/2}$	?$_{9/2}$	29 116.26	41 641.97	2 653
7 988.627	– ; –	$^4\mathrm{D}_{5/2}$	?$_{3/2}$	27 715.66	40 230.01	2 484
7 992.167	– ; –	$^2\mathrm{P}_{3/2}$	$z\ ^4\mathrm{D}_{5/2}$	33 676.41	21 167.61	5 811 ^{n}
8 021.211	– ; –	?$_{3/2}$	$z\ ^2\mathrm{P}_{1/2}$	43 964.50	31 500.99	3 173 ^{n}
8 022.09 ^{b}	6 ; 5	$e\ ^6\mathrm{F}_{1/2}$	?$_{3/2}$	41 151.26	28 689.31	4 206
8 037.679	– ; –	?$_{3/2}$	?$_{3/2}$	49 961.52	37 523.54	3 176 ^{n}
8 042.291	– ; –	?$_{9/2}$	?$_{7/2}$	58 079.07	45 648.26	3 095
8 068.98 ^{a}	15 ; 25	$a\ ^2\mathrm{H}_{9/2}$	$z\ ^6\mathrm{D}_{7/2}$?	15 391.01	27 780.62	6 045
8 079.130	– ; –	$^4\mathrm{D}_{3/2}$	?$_{5/2}$	27 412.36	39 786.52	3 502
8 084.736	– ; –	$^2\mathrm{G}_{7/2}$	?$_{9/2}$	29 276.39	41 641.97	2 653
8 088.85	– ; 2	$^4\mathrm{D}_{7/2}$	$^4\mathrm{G}_{7/2}$	25 894.09	38 253.39	3 937
8 100.11 ^{a}	5 ; 15	$a\ ^2\mathrm{G}_{7/2}$	$z\ ^2\mathrm{D}_{5/2}$	9 705.38	22 047.45	6 256
8 107.601	– ; –	$^2\mathrm{D}_{3/2}$	$x\ ^6\mathrm{D}_{1/2}$	32 187.39	44 518.10	2 876

Table 1. *Continued.*

	intensity in	transition		energy levels / cm^{-1}		
λ/Å	[20] ; [19]	des. even	des. odd	even	odd	λ_F/Å
8 108.471	– ; –	$^2D_{5/2}$	$x\ ^6D_{3/2}$	32 916.84	45 246.22	2 940
8 108.579	– ; –	$?_{5/2}$	$?_{7/2}$	44 461.60	32 132.38	3 318 [n]
8 130.111	– ; –	$^2D_{3/2}$	$?_{3/2}$	32 187.39	44 483.96	2 601
8 141.232	– ; –	$^4F_{5/2}$	$y\ ^4G_{5/2}$?	24 546.20	36 825.97	2 714
8 167.470	– ; –	$?_{9/2}$	$y\ ^6F_{11/2}$	58 079.07	45 838.75	3 077 [n]
8 180.74	5 ; –	$^4D_{5/2}$	$?_{7/2}$	27 715.66	39 936.13	2 779
8 187.846	– ; –	$^2H_{9/2}$	$?_{7/2}$	32 192.70	44 402.56	2 577
8 193.896	– ; –	$?_{3/2}$	$?_{3/2}$	49 961.52	37 760.67	2 647 [n]
8 195.131	– ; –	$^2D_{3/2}$	$?_{5/2}$	32 187.39	44 386.40	2 608
8 200.501	– ; –	$^6S_{5/2}$	$?_{7/2}$	32 502.38	44 693.40	2 857
8 207.736	– ; –	$a\ ^4D_{3/2}$	$?_{1/2}$	21 381.01	33 561.28	2 978
8 232.683	– ; –	$^2I_{11/2}$	$?_{9/2}$	29 498.60	41 641.97	2 653
8 260.087	– ; –	$^2G_{7/2}$	$?_{5/2}$	30 879.72	42 982.80	2 562
8 281.62 [a]	75 ; 50	$a\ ^6D_{3/2}$	$z\ ^2D_{5/2}$	9 975.81	22 047.45	6 256
8 282.831	– ; –	$^4D_{3/2}$	$?_{1/2}$	24 275.96	36 345.80	3 299
8 343.848	– ; –	$^6S_{5/2}$	$?_{3/2}$	32 502.38	44 483.96	2 601
8 349.909	– ; –	$^2H_{9/2}$	$?_{7/2}$	32 192.70	44 165.58	4 344
8 355.404	– ; –	$^2G_{7/2}$	$?_{5/2}$	30 879.72	42 844.73	2 718
8 359.764	– ; –	$^2D_{3/2}$	$?_{1/2}$	32 187.39	44 146.16	2 624
8 411.919	– ; –	$^2D_{3/2}$	$?_{3/2}$	25 876.05	37 760.67	2 647
8 412.345	– ; –	$^6S_{5/2}$	$?_{5/2}$	32 502.38	44 386.40	2 608
8 437.616	– ; –	$?_{3/2}$	$?_{1/2}$	43 964.50	55 812.93	3 849 [n]
8 437.701	– ; –	$?_{5/2}$	$?_{5/2}$	36 689.67	48 537.97	3 681
8 438.056	– ; –	$^6S_{5/2}$	$?_{3/2}$	32 502.38	44 350.19	3 019
8 438.329	– ; –	$^4F_{3/2}$	$?_{5/2}$	43 275.47	31 428.05	3 954
8 456.949	– ; –	$^2P_{3/2}$	$z\ ^4F_{3/2}$	33 676.41	21 855.07	4 574 [n]
8 469.401	– ; –	$a\ ^4D_{3/2}$	$?_{5/2}$	21 381.01	33 184.97	3 012
8 470.987	– ; –	$^4D_{1/2}$	$?_{3/2}$	26 743.95	38 545.70	3 736
8 498.466	– ; –	$^4D_{1/2}$	$y\ ^6F_{1/2}$	26 743.95	38 507.54	3 503
8 513.739	– ; –	$^2H_{11/2}$	$y\ ^6F_{9/2}$	33 064.15	44 806.64	3 069
8 532.276	– ; –	$?_{3/2}$	$?_{1/2}$	44 095.95	55 812.93	4 012 [n]
8 538.950	– ; –	$?_{5/2}$	$z\ ^4F_{7/2}$	36 689.67	24 981.85	5 163 [n]
8 559.519	– ; –	$?_{5/2}$	$?_{5/2}$	36 689.67	48 369.35	2 585
8 642.812	– ; –	$^2D_{5/2}$	$?_{3/2}$	32 916.84	44 483.96	2 601
8 646.604	– ; –	$a\ ^4G_{5/2}$	$?_{5/2}$	21 622.92	33 184.97	3 012
8 686.803	– ; –	$?_{5/2}$	$z\ ^6F_{5/2}$	36 689.67	25 181.12	32 23 [c]
8 693.924	– ; –	$^2D_{5/2}$	$?_{7/2}$	38 459.58	26 960.46	4 006 [n]
8 716.328	– ; –	$^2D_{5/2}$	$?_{5/2}$	32 916.84	44 386.40	2 608
8 743.933	– ; –	$^2D_{5/2}$	$?_{3/2}$	32 916.84	44 350.19	2 361
8 752.027	– ; –	$^2D_{5/2}$	$?_{7/2}$	38 459.58	49 882.36	2 898
8 784.972	– ; –	$?_{5/2}$	$?_{7/2}$	36 689.67	48 069.61	2 575
8 786.118	– ; –	$^6S_{5/2}$	$?_{5/2}$	32 502.38	43 880.84	2 504
8 797.772	– ; –	$^2D_{3/2}$	$?_{5/2}$	32 187.39	43 550.78	2 406
8 807.166	– ; –	$?_{7/2}$	$?_{7/2}$	50 992.51	39 641.24	3 029

Table 1. *Continued.*

	intensity in	transition		energy levels / cm^{-1}		
λ/Å	[20] ; [19]	des. even	des. odd	even	odd	λ_F/Å
8 827.349	– ; –	$^4D_{1/2}$	$?_{1/2}$	22 235.97	33 561.28	2 978
8 834.82	– ; 2	$a\ ^4P_{3/2}$	$z\ ^6G_{3/2}$	6 068.91	17 384.65	6 502
8 893.168	– ; –	$?_{5/2}$	$?_{7/2}$	36 689.67	47 931.16	2 584
8 895.605	– ; –	$?_{5/2}$	$?_{5/2}$	36 689.67	47 928.08	2 615
8 936.51	– ; 2	$a\ ^4H_{11/2}$	$?_{9/2}$	22 428.56	33 615.49	3 371
8 974.489	– ; –	$^2D_{5/2}$	$?_{7/2}$	38 459.58	49 599.21	3 990
8 940.480	– ; –	$^2I_{13/2}$	$^4I_{15/2}$	30 542.35	41 724.35	5 490
8 993.352	– ; –	$?_{3/2}$	$?_{1/2}$	49 961.52	38 845.25	2 573 ^{n}
9 048.596	– ; –	$^6S_{5/2}$	$?_{5/2}$	32 502.38	43 550.78	2 406
9 074.615	– ; –	$^4D_{1/2}$	$?_{3/2}$	26 743.95	37 760.67	2 647
9 105.70	– ; 3	$a\ ^4H_{9/2}$	$?_{7/2}$	21 153.33	32 132.38	3 318

Table 2. Ta I - lines classified by means of laser induced fluorescence. The relative intensities of these lines were taken from [19,20]. Lines with no intensity numbers are calculated lines which are not listed in the above mentioned sources. Lines with a second classification given in [20], are labelled superscripted *d*. Lines where the difference between the vacuum wavenumbers which are given in [20] or [19] and the calculated wavenumbers (difference of energies) exceeds 0.15 cm^{-1} are labelled superscripted *b*. λ_{exc} is the wavelength of the exciting laser light.

	intensity in	transition		energy levels / cm^{-1}		
λ_F/Å	[20] ; [19]	des. even	des. odd	even	odd	λ_{exc}/Å
2 190.59	– ; 10	$a\ ^4F_{7/2}$	$?_{7/2}$	3 963.92	49 599.21	8 974
2 488.207	– ; 5	$a\ ^2G_{7/2}$	$?_{7/2}$	9 705.38	49 882.36	8 752
2 535.518	– ; –	$a\ ^4F_{7/2}$	$^2H_{9/2}$	3 963.92	43 391.71	7 003
2 574.379 ^{d}	150 ; 80	$a\ ^2G_{7/2}$	$?_{5/2}$	9 705.38	48 537.97	8 437
2 653.274	2 600 ; 200	$a\ ^4F_{7/2}$	$?_{9/2}$	3 963.92	41 641.97	7 981
2 659.655	35 ; 15	$^6D_{3/2}$	$?_{5/2}$	10 950.22	48 537.97	8 437
2 741.168 ^{d}	150 ; –	$^2H_{9/2}$	$?_{9/2}$	10 690.32	47 160.34	7 092
2 775.346	– ; 80	$a\ ^4F_{9/2}$	$?_{9/2}$	5 621.04	41 641.97	8 232
2 802.493	– ; 15	$a\ ^2D_{5/2}$	$?_{5/2}$	12 865.97	48 537.97	8 437
2 844.251 ^{d}	640 ; 400	$^2H_{9/2}$	$y\ ^6F_{11/2}$	10 690.32	45 838.75	7 825
2 850.491	1 500 ; 200	$a\ ^4F_{3/2}$	$?_{1/2}$	0.00	35 071.36	7 788
2 862.385	– ; 2	$a\ ^6D_{7/2}$	$?_{9/2}$	12 234.76	47 160.34	7 092
2 892.000	– ; 80	$a\ ^2H_{11/2}$	$?_{11/2}$	15 114.14	49 682.23	4 861
2 915.337 ^{d}	170 ; 150	$a\ ^2H_{9/2}$	$?_{11/2}$	15 391.01	49 682.23	4 861
2 922.415	– ; 10	$a\ ^2H_{9/2}$	$?_{7/2}$	15 391.01	49 599.21	8 974
2 956.938	– ; –	$a\ ^6D_{9/2}$	$?_{9/2}$	13 351.45	47 160.34	7 092
2 978.754	170 ; 200	$a\ ^4F_{3/2}$	$?_{1/2}$	0.00	33 561.28	3 633
3 029.534	– ; 5	$?_{7/2}$	$?_{5/2}$	50 992.51	17 993.74	8 807
3 075.322	– ; 18	$a\ ^2H_{11/2}$	$?_{9/2}$	15 114.14	47 621.80	5 516
3 077.245	360 ; 150	$a\ ^6D_{9/2}$	$y\ ^6F_{11/2}$	13 351.45	45 838.75	7 825
3 110.103	– ; 3	$a\ ^6D_{1/2}$	$?_{1/2}$	9 758.97	41 902.92	6 899
3 119.594 ^{d}	75 ; 18	$a\ ^2H_{11/2}$	$?_{9/2}$	15 114.14	47 160.34	7 092
3 131.216	– ; 5	$a\ ^6D_{3/2}$	$?_{1/2}$	9 975.81	41 902.92	6 899

Table 2. *Continued.*

	intensity in	transition		energy levels / cm^{-1}		
λ_F/Å	[20] ; [19]	des. even	des. odd	even	odd	λ_exc /Å
3 178.266	– ; 15	$a\,^4\mathrm{P}_{3/2}$	$?_{3/2}$	6 068.91	37 523.54	6 287
3 203.735 [b]	– ; 3	$a\,^6\mathrm{D}_{3/2}$	$?_{1/2}$	9 975.81	41 179.90	6 925
3 219.585 [b,d]	– ; 20	$a\,^2\mathrm{G}_{7/2}$	$?_{7/2}$	9 705.38	40 755.90	6 500
3 229.880 [b]	– ; 35	$^6\mathrm{D}_{3/2}$	$?_{1/2}$	10 950.22	41 902.92	6 899
3 444.681	– ; 5	$a\,^4\mathrm{P}_{1/2}$	$?_{1/2}$	6 049.42	35 071.36	7 788
3 446.997	– ; –	$a\,^4\mathrm{P}_{3/2}$	$?_{1/2}$	6 068.91	35 071.36	7 788
3 520.417	– ; –	$a\,^6\mathrm{D}_{5/2}$	$?_{7/2}$	11 243.63	39 641.24	7 272
3 535.404 [b]	– ; 15	$a\,^2\mathrm{H}_{11/2}$	$?_{9/2}$	15 114.14	43 391.71	7 003
3 537.630	– ; –	$a\,^4\mathrm{G}_{5/2}$	$?_{7/2}$	21 622.92	49 882.36	8 752
3 609.177	– ; 8	$a\,^2\mathrm{H}_{9/2}$	$?_{9/2}$	15 391.01	43 090.28	7 355
3 636.336	– ; –	$a\,^4\mathrm{P}_{3/2}$	$?_{1/2}$	6 068.91	33 561.28	8 207
3 681.243	40 ; 15	$a\,^4\mathrm{D}_{3/2}$	$?_{5/2}$	21 381.01	48 537.97	8 437
3 706.055	– ; 2	$a\,^4\mathrm{H}_{7/2}$	$?_{9/2}$	20 646.54	47 621.80	5 516
3 725.013	– ; 5	$^4\mathrm{H}_{7/2}$	$?_{7/2}$	22 761.21	49 599.21	8 974
3 779.146 [b]	– ; 2	$a\,^2\mathrm{G}_{7/2}$	$z\,^4\mathrm{H}_{7/2}?$	9 705.38	36 159.13	6 662
3 780.173 [b]	– ; 30	$a\,^4\mathrm{G}_{5/2}$	$?_{7/2}$	21 622.92	48 069.61	6 421
3 849.42	40 ; 4	$?_{3/2}$	$?_{5/2}$	43 964.50	17 993.74	8 437
3 875.21	– ; 5	$a\,^2\mathrm{H}_{11/2}$	$z\,^4\mathrm{I}_{13/2}$	15 114.14	40 911.83	5 746
3 909.332 [d]	65 ; 15	$?_{3/2}$	$z\,^4\mathrm{D}_{5/2}$	46 740.13	21 167.61	7 013
3 925.241	– ; 25	$^2\mathrm{H}_{9/2}$	$z\,^4\mathrm{H}_{7/2}$?	10 690.32	36 159.13	6 662
3 954.294	40 ; 5	$^4\mathrm{F}_{3/2}$	$?_{5/2}$	43 275.47	17 993.74	6 936
3 968.16	– ; 4	$a\,^4\mathrm{H}_{11/2}$	$?_{9/2}$	22 428.56	47 621.80	5 516
4 159.976 [b]	– ; 5	$a\,^2\mathrm{H}_{9/2}$	$?_{9/2}$	15 391.01	39 422.40	7 460
4 232.940	35 ; –	$^4\mathrm{F}_{3/2}$	$z\,^4\mathrm{D}_{3/2}$	43 275.47	19 657.78	6 936
4 364.838 [b]	45 ; 15	$a\,^4\mathrm{H}_{7/2}$	$?_{5/2}$	20 646.54	43 550.78	7 889
4 459.763 [b,d]	95 ; 30	$a\,^2\mathrm{F}_{5/2}$	$?_{7/2}$	17 224.47	39 641.24	7 272
4 789.279 [d]	– ; 4	$^4\mathrm{G}_{5/2}$	$?_{5/2}$	23 512.34	44 386.40	8 412
5 041.869	– ; 4	$a\,^4\mathrm{H}_{9/2}$	$?_{7/2}$	21 153.33	40 981.79	6 939
5 132.32	– ; 2	$^4\mathrm{H}_{9/2}$	$^2\mathrm{H}_{9/2}$	23 912.89	43 391.71	7 003
5 260.429	– ; 8	$^4\mathrm{F}_{5/2}$	$?_{5/2}$	24 546.20	43 550.78	7 889
5 373.013	20 ; 12	$?_{3/2}$	$y\,^4\mathrm{D}_{5/2}$	46 740.13	28 133.88	7 013
5 472.215	– ; 2	$a\,^4\mathrm{H}_{9/2}$	$?_{9/2}$	21 153.33	39 422.40	6 892
5 628.20 [d]	13 ; –	$^4\mathrm{F}_{3/2}$	$y\,^4\mathrm{D}_{1/2}$	43 275.47	25 512.63	6 936
5 904.333	– ; 2	$a\,^4\mathrm{H}_{11/2}$	$z\,^4\mathrm{H}_{13/2}$	22 428.56	39 360.68	7 495
6 129.684 [b]	– ; 2	$a\,^4\mathrm{D}_{1/2}$	$?_{3/2}$	22 235.97	38 545.70	7 005
6 218.99 [d]	– ; 5	$?_{3/2}$	$y\,^6\mathrm{D}_{3/2}$	46 740.13	30 664.66	7 013
6 239.189	– ; 5	$^4\mathrm{H}_{9/2}$	$?_{7/2}$	23 912.89	39 936.13	8 180
6 626.18 [b]	– ; 3	$^4\mathrm{D}_{7/2}$	$?_{9/2}$	25 894.09	40 981.79	6 939
7 175.77	– ; 2	$^4\mathrm{F}_{3/2}$	$?_{5/2}$	43 275.47	29 343.46	6 936

The intensities of the spectral lines were again taken from [19,20]. For new lines, which are listed without an intensity entry, we have calculated the wavelengths using the wavenumber difference of the involved levels.

Mismatches, *i.e.* cases where the difference between the wavenumber according to the entry in [19] or [20] and the wavenumber that was calculated by means of the energy difference of the involved levels exceeds 0.15 cm^{-1}, are emphasised in Tables 1 and 2. An additional classification (blend) for these lines might be possible.

In some cases, especially for transitions between levels with $J' = 1/2$ having a large hyperfine splitting to levels with $J = 1/2$ or $3/2$ having a comparably small hyperfine splitting, two groups of the hyperfine components are well separated and listed in the tables as two separate lines, so it was necessary to calculate the correct center of gravity wavelength. This concerns the lines $\lambda = 3\,633.760$ Å where the entries $\lambda = 3\,633.75$ Å and $\lambda = 3\,633.788$ Å were given in [19,20] and $\lambda = 7\,788.810$ Å where the two hfs component groups were given at $\lambda = 7\,788.64$ Å and $\lambda = 7\,788.95$ Å in [19] (see Tab. 1).

In Table 3 we have listed the incorrect classifications of spectral lines in [20] and if it was possible the correct classification is already given in Tables 1 or 2.

The J-values of three odd parity levels (44 402.56 cm^{-1}, 46 060.6 cm^{-1} and 47 621.80 cm^{-1}) given in [16] were incorrect. They are listed with the corrected J-value in Table 5. By evaluating the hfs of lines, which are combinations with these levels, we redetermined the J-values beyond all doubt. So we used the hyperfine structure as a tool for the evaluation of fine structure data.

In Tables 4 and 5 we have summarised the hyperfine interaction constants A and B of energy levels of which up to now no hfs-data were available.

New levels were mostly found by excitation of an unclassified line given in the tables. A good fit of the recorded signal gave us the opportunity to use the J-values and the A- and B-factors of the involved levels as a fingerprint. By comparison with values of known levels we were able to identify either the upper or the lower level of the transition and calculate the energy of the new level using the wavenumber of the line as described in [5].

The situation was more difficult if both levels were unknown or at least no hyperfine data were available. Then, we succeeded by taking a detailed look at the fluorescence lines of the transition which implies a very precise determination of their wavelengths. If the observed fluorescence lines were not classified, we searched for differences of level energies corresponding to the wavenumber differences of the fluorescence lines. With this strategy it was always possible to find at least two energy levels with the same wavenumber difference as two observed fluorescence lines indicating a common upper level for which the energy could be calculated easily. An example is the line $\lambda = 7\,092.16$ Å which was identified as a transition between the new levels $T' = 33\,064.15$ cm^{-1} and $T = 47\,160.34$ cm^{-1}. A typical LIF-recording of the hyperfine structure is shown in Figure 1.

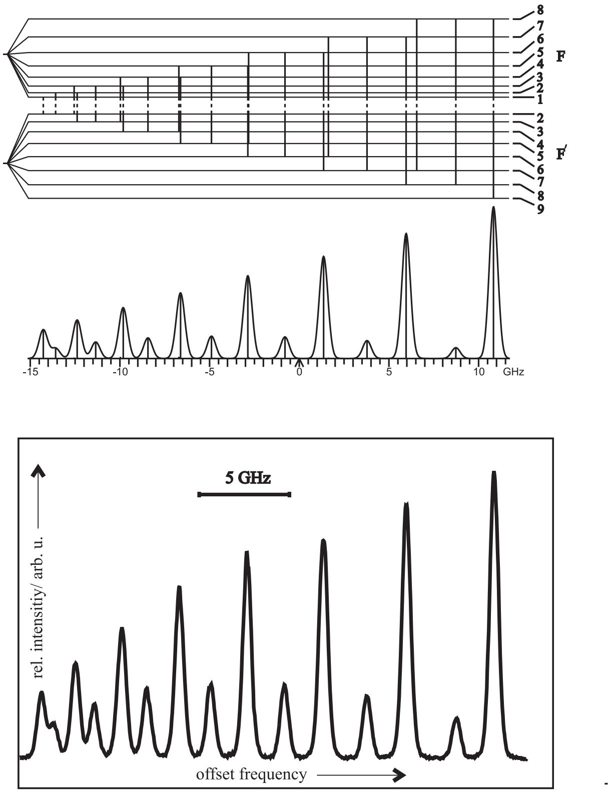

Fig. 1. Hyperfine structure of the Ta I-line $\lambda = 7\,092.16$ Å (transition between the new levels $T' = 33\,064.15$ cm^{-1}, $J' = 11/2$ and $T = 47\,160.34$ cm^{-1}, $J = 9/2$). Above: simulation of the hfs-spectra with the evaluated A- and B-factors. Please, note that the hyperfine multiplet of the lower level lies inverted. Below: typical LIF-recording of the spectrum.

One of the new levels was found by revealing a wrong classification of one of the 20 strongest lines in the spectrum of tantalum. The line $\lambda = 2\,653.274$ Å which was listed in [20] with an intensity of 2 600 was classified as a transition from $T = 2\,010.10$ cm^{-1} to $T = 39\,688.20$ cm^{-1}. It turned out that it was not possible to combine the upper level with several well known levels. Therefore, we believe the energy level $T = 39\,688.20$ cm^{-1} probably not to exist.

Tentatively, we positioned a new energy level at $T = 41\,641.97$ cm^{-1} using the wavenumber of the above mentioned line, assuming the lower level of the transition to be $T = 3\,963.92$ cm^{-1}. We were able to excite this new level with three lines lying in the spectral region of our Ti:sapphire ring-laser and we could determine J to $9/2$ definitely. All lines showed strong laser induced fluorescence at $\lambda = 2\,653.274$ Å.

Generally, we would like to emphasise that after discovery, every new energy level was excited by at least one additional laser transition to assure its existence beyond any doubt. Tables 6 and 7 contain all the evaluated data concerning these new levels. Some of them were already included in a parametric fine- and hyperfine structure analysis and their configuration and designation could be confirmed in [21].

Table 3. Wrongly classified lines of Ta I in [20]. The relative intensities of these lines were taken from [19,20]. The correct classification is listed in Tables 1 or 2, except of the lines labelled superscripted g which now remain as unclassified lines.

λ/Å	intensity in [20] ; [19]	transition des. even	transition des. odd	energy levels / cm^{-1} even	energy levels / cm^{-1} odd
2 473.13 ^{g}	150 ; 20	$a\,{}^4\mathrm{F}_{7/2}$	$?_{5/2}$	3 963.92	44 386.40
2 653.274	2 600 ; 200	$a\,{}^4\mathrm{F}_{5/2}$	$?_{5/2}$	2 010.10	39 688.20
2 798.404 ^{g}	190 ; 150	$a\,{}^4\mathrm{F}_{7/2}$	$?_{5/2}$	3 963.92	39 688.20
3 077.245	360 ; 150	${}^2\mathrm{H}_{9/2}$	$y\,{}^6\mathrm{F}_{7/2}$	10 690.32	43 177.37
4 556.354 ^{g}	85 ; 200	$a\,{}^6\mathrm{D}_{5/2}$	$?_{5/2}$	11 243.63	33 184.97
5 115.843	110 ; 80	$a\,{}^4\mathrm{D}_{7/2}$	$?_{5/2}$	26 575.02	46 116.93

Table 4. Results for the A- and B-constants of experimentally exploited levels with even parity of Ta I. These levels were listed in [16] but until now no hyperfine data were available. One level, which was considered to be non-existent in [6], is labelled superscripted h.

config.	des.	energy /cm^{-1}	A/MHz	B/MHz	line(s) under study /Å
$5d^3 6s^2$	${}^2\mathrm{P}_{3/2}$	15 903.77	246.3(20)	17.3(30)	7 715
$5d^3 6s^2$	$a\,{}^2\mathrm{H}_{9/2}$	15 391.01	298.4(10)	1 993(30)	7 815, 8 068
$5d^4(a\,{}^5\mathrm{D})6s$	$a\,{}^4\mathrm{D}_{3/2}$	2 1381.01	−272.7(10)	408(5)	6 472, 6 577, 7 454
$5d^4(a\,{}^3\mathrm{G})6s$	${}^4\mathrm{G}_{7/2}$	24 917.90	−120.5(10)	−1 362(15)	6 339, 7 264
	$?_{3/2}$	43 964.50	116.8(30)	660(20)	4 852
	$?_{3/2}$	44 095.95	65.4(10)	589(4)	7 937
	$?_{5/2}$	46 981.89	1 126(5)	−703(61)	6 896
	$?_{7/2}$	47 817.16 ^{h}	579.2(20)	901(17)	6 981

Table 5. Results for the A- and B-constants of experimentally exploited levels with odd parity of Ta I. These levels are listed in [16] but up to now no hyperfine data were available. Levels which are given in [16] with a wrong J-value are labelled superscripted j, levels with a slight correction of the energy value are labelled superscripted k.

config.	des.	energy /cm^{-1}	A/MHz	B/MHz	line(s) under study /Å
	$?_{5/2}$	17 993.74	999.5(10)	−137(5)	6 254, 7 125, 7 758
$5d^3 6s(a\,{}^3\mathrm{F})6p$	$z\,{}^4\mathrm{D}_{3/2}$	19 657.78	642.0(20)	−274(5)	7 346, 7 356
$5d^2 6s^2(a\,{}^3\mathrm{P})6p$	$z\,{}^2\mathrm{D}_{5/2}$	22 047.45	670.4(10)	58.5(20)	7 814, 8 100, 8 281
$5d^3 6s(a\,{}^3\mathrm{F})6p$	$z\,{}^4\mathrm{D}_{7/2}$	23 926.68	866.8(5)	−79(8)	7 882
	$?_{9/2}$	25 185.89	583.6(5)	15(5)	7 719
	$?_{7/2}$	30 590.95	329(20)	988(150)	7 569
	$?_{5/2}$	31 428.05	−21(3)	812(50)	7 118, 8 438
$5d^2 6s^2(a\,{}^3\mathrm{P})6p$	$z\,{}^2\mathrm{P}_{1/2}$	31 500.99	−361.5(30)	0	4 864, 7 937
	$?_{7/2}$	32 132.38	−53(5)	1 623(150)	7 818
	$?_{3/2}$	32 214.94	−69.5(10)	−1 104(30)	7 869, 8 282
	$?_{5/2}$	33 184.97	1 109(3)	−1 458(10)	8 646
	$?_{9/2}$	33 497.15	342(1)	2 483(20)	7 779
	$?_{3/2}$	35 242.94	1 641.3(10)	1 224.5(20)	7 340
	$?_{7/2}$	35 746.18	499.8(15)	981(20)	7 699
	$?_{11/2}$	35 813.47	891.3(5)	2 654(4)	7 469
	$?_{1/2}$	36 345.8	1 058.4(15)	0	7 085, 8 282
	$?_{9/2}$	36 631.15	967.6(4)	336(7)	7 207
$5d^3 6s(a\,{}^3\mathrm{G})6p$	$y\,{}^4\mathrm{G}_{5/2}$?	36 825.97	740.3(11)	585(13)	6 472, 7 509,8 141
	$?_{3/2}$	37 523.54	−172(8)	−251(27)	6 287
	$?_{3/2}$	37 760.67	1 089.2(10)	−1 326(7)	8 411, 9 074

Table 5. *Continued.*

config.	des.	energy /cm^{-1}	A/MHz	B/MHz	line(s) under study /Å
$5d^4(a\ ^5\mathrm{D})6p$	$y\ ^6\mathrm{F}_{1/2}$	38 507.54	−510.6(5)	0	8 498, 5 837
	?$_{3/2}$	38 545.70	848.0(5)	708(3)	8 470
	?$_{5/2}$	38 753.75	−125.2(10)	193(17)	7 036, 7 763
	?$_{3/2}$	38 994.33	291.6(5)	−300(11)	7 620
	?$_{5/2}$	39 059.52	260.6(10)	−657(20)	5 733, 7 593
	?$_{9/2}$	39 422.40	389.8(4)	−764(7)	6 445, 7 389
$5d^36s(a\ ^3\mathrm{H})6p$	$z\ ^4\mathrm{I}_{11/2}$?	39 468.63	517.4(20)	3 902(50)	6 266, 7 435
	?$_{3/2}$	40 230.01	165.1(15)	−710(10)	7 988
	?$_{1/2}$	40 244.74	1 369(1)	0	7 404
	?$_{7/2}$	40 333.03	86.4(6)	−403(14)	6 811, 7 923
	?$_{3/2}$	40 339.2	346.3(20)	471(20)	7 733, 7 919
	?$_{5/2}$	40 510.45	734.8(20)	558(20)	4 322, 7 632
$5d^36s(a\ ^3\mathrm{H})6p$	$z\ ^4\mathrm{I}_{13/2}$	40 911.83	838.9(5)	5 451(42)	5 746, 6 714
	?$_{1/2}$	41 179.9	3 594(3)	0	6 925
	?$_{5/2}$	41 879.23	491.7(12)	575(17)	6 910
	?$_{1/2}$	41 902.92	679(10)	0	6 899
	?$_{3/2}$	42 408.16	294.7(15)	65(10)	5 513
	?$_{7/2}$	42 751.72	−110.8(20)	−834(30)	5 491, 5 753, 7 418
	?$_{5/2}$	42 844.73	998.3(15)	−744(25)	8 355
	?$_{5/2}$	42 982.8	188(10)	848(150)	8 260
	?$_{9/2}$	43 090.28	−20(1)	−702(20)	7 355
	?$_{3/2}$	43 167.07	188.4(13)	−360(10)	4 918
	?$_{5/2}$	43 239.22	436.4(5)	557(15)	5 685
$5d^4(a\ ^5\mathrm{D})6p$	$y\ ^4\mathrm{P}_{1/2}$	43 478.20	2 054(10)	0	6 222
	?$_{5/2}$	43 550.78	−54(4)	178(29)	7 889
	?$_{5/2}$	43 880.84	654.4(20)	382(23)	8 786
	?$_{1/2}$	44 146.16	91(6)	0	8 359
	?$_{7/2}$	44 165.58	666.2(10)	117(20)	5 471, 8 349
	?$_{3/2}$	44 350.19	1 357.6(10)	423(5)	8 438
	?$_{5/2}$	44 386.40	115.3(10)	886(14)	8 412
	?$_{7/2}$	44 402.56 [j]	508.9(14)	282(30)	4 879, 8 187
	?$_{3/2}$	44 483.96	−7.3(17)	369(12)	8 343
$5d^4(a\ ^5\mathrm{D})6p$	$x\ ^6\mathrm{D}_{1/2}$	44 518.10	−80.3(20)	0	8 107
	?$_{7/2}$	44 693.40	398.0(14)	1 560(26)	5 517
$5d^4(a\ ^5\mathrm{D})6p$	$y\ ^6\mathrm{F}_{9/2}$	44 806.64	34(1)	−79(20)	8 513
	?$_{11/2}$	45 057.34	194.8(5)	3 505(17)	6 425
	?$_{7/2}$	45 114.71	−318.3(5)	1 449(32)	7 023
$5d^4(a\ ^5\mathrm{D})6p$	$x\ ^6\mathrm{D}_{3/2}$	45 246.22	92.1(10)	949(15)	7 844
$5d^4(a\ ^5\mathrm{D})6p$	$x\ ^6\mathrm{D}_{5/2}$	45 255.98	297.7(8)	1 269(8)	6 953
	?$_{7/2}$	45 648.26	459.5(5)	−1 191(10)	7 604
	?$_{3/2}$	45 723.58	373(10)	−519(60)	7 806
$5d^4(a\ ^5\mathrm{D})6p$	$y\ ^6\mathrm{F}_{11/2}$	45 838.75	164.7(10)	1 363(35)	7 825
	?$_{9/2}$	46 060.6 [j]	133.8(18)	1 889(62)	4 833
	?$_{5/2}$	46 116.93	1 047(25)	752(200)	7 343
	?$_{7/2}$	46 172.44	−135.5(20)	−609(60)	7 313
	?$_{3/2}$	46 176.76	58(2)	94(40)	4 871

Table 5. *Continued.*

config.	des.	energy /cm^{-1}	A/MHz	B/MHz	line(s) under study /Å
$5d^4(a\ ^5\mathrm{D})6p$	$y\ ^4\mathrm{P}_{5/2}$	46 323.31	−335.3(5)	814(33)	7 233
$5d^4(a\ ^5\mathrm{D})6p$	$x\ ^6\mathrm{D}_{7/2}$	46 409.79	248.5(20)	84(70)	6 437, 7 188
	$?_{3/2}$	46 887.79	374.2(30)	−6(50)	6 949
	$?_{7/2}$	47 013.02	639(3)	1 606(60)	7 092
	$?_{5/2}$	47 397.06	−117(15)	1 133(400)	6 904
	$?_{9/2}$	47 621.80 [j,k]	195.1(6)	1 669(16)	6 479, 6 867
	$?_{7/2}$	47 625.01	450(4)	1 610(58)	6 797
$5d^4(a\ ^5\mathrm{D})6p$	$x\ ^6\mathrm{D}_{9/2}$	47 799.81	40.5(17)	−2 702(48)	6 784
	$?_{5/2}$	47 928.08	215(10)	470(150)	6 480
	$?_{7/2}$	47 931.16	271.8(20)	1 366(40)	6 479, 8 893
	$?_{7/2}$	48 069.61	268.7(20)	2 155(30)	6 421, 8 784
	$?_{5/2}$	48 369.35	190(4)	538(62)	8 559
	$?_{9/2}$	49 149.30	847(4)	3 575(122)	5 030
	$?_{7/2}$	49 599.21	114(3)	74(49)	8 974
	$?_{7/2}$	49 882.36 [k]	581(2)	473(35)	8 752

Table 6. Energy, quantum numbers and hyperfine constants of the newly discovered tantalum energy levels with even parity. Configuration and designation are taken from [21] with the exception of the level 43 275.47 cm^{-1}, which we have assigned to the $e\ ^4\mathrm{F}_{3/2}$, and the level 44 918.67 cm^{-1}, which we have assigned to the $e\ ^4\mathrm{F}_{5/2}$, belonging to the configuration $5d^36s7s$. This has been confirmed by [22].

config.	des.	energy /cm^{-1}	A/MHz	B/MHz	line(s) under study /Å
$5d^4(^5\mathrm{D})6s$	$^4\mathrm{D}_{3/2}$	24 275.96	1 489.8(10)	71(2)	7 005
$5d^4(^3\mathrm{D})6s$	$^4\mathrm{D}_{5/2}$	25 655.36	1 201.5(10)	−55.6(30)	6 578, 7 676
$5d^36s^2$	$^2\mathrm{D}_{3/2}$	25 876.05	−75.7(10)	1 215(10)	7 343, 7 620, 7 952
$5d^4(^5\mathrm{D})6s$	$^4\mathrm{D}_{7/2}$	25 894.09	5.4(5)	−1946(10)	6 626, 8 088
$5d^4(^3\mathrm{D})6s$	$^4\mathrm{D}_{1/2}$	26 743.95	−1 749.6(15)	0	6 925, 7 404, 8 470
$5d^4(^3\mathrm{D})6s$	$^4\mathrm{D}_{3/2}$	27 412.36	26(6)	461(60)	7 632, 8 079
$5d^4(^3\mathrm{D})6s$	$^4\mathrm{D}_{5/2}$	27 715.66	709.5(20)	1 387(10)	7 988, 8 180
$5d^4(^1\mathrm{G})6s$	$^2\mathrm{G}_{7/2}$	29 276.39	−288.5(5)	−702(10)	7 418
$5d^4(^1\mathrm{I})6s$	$^2\mathrm{I}_{11/2}$	29 498.60	−243.3(8)	2 093(15)	6 425, 7 195
$5d^4(^3\mathrm{G})6s$	$^2\mathrm{G}_{7/2}$	30 879.72	230.5(10)	−194(35)	7 758
$5d^4(^3\mathrm{D})6s$	$^2\mathrm{D}_{3/2}$	32 187.39	1 202.8(25)	705(20)	8 359, 8 670
$5d^4(^3\mathrm{H})6s$	$^2\mathrm{H}_{9/2}$	32 192.70	1 015.3(8)	323(30)	6 479, 8 349
$5d^5$	$^6\mathrm{S}_{5/2}$	32 502.38	−501(2)	26(10)	7 188, 7 844, 8 438
$5d^4(^3\mathrm{D})6s$	$^2\mathrm{D}_{5/2}$	32 916.84	75(4)	1 104(50)	7 092
$5d^4(^3\mathrm{H})6s$	$^2\mathrm{H}_{11/2}$	33 064.15	−303.5(10)	1 783(20)	5 898, 7 092, 8 013
$5d^4(^3\mathrm{P})6s$	$^2\mathrm{P}_{3/2}$	33 676.41	−1298(2)	826(10)	7 992
	$?_{5/2}$	36 689.67	−0.4(17)	2 193(11)	8 538
$5d^4(^1\mathrm{D})6s$	$^2\mathrm{D}_{5/2}$	38 459.58	1 745(3)	902(32)	8 693, 8 752
$5d^36s7s$	$^4\mathrm{F}_{3/2}$	43 275.47	−558.9(3)	−719(4)	6 936
$5d^36s7s$	$^4\mathrm{F}_{5/2}$	44 918.67	1 031.8(10)	−717(10)	7 869
	$?_{3/2}$	46 740.13	1 558.2(15)	814(15)	7 013
	$?_{3/2}$	49 961.52	−262(3)	409(18)	8 193
	$?_{7/2}$	50 992.51	870.6(8)	134(23)	7 847
	$?_{9/2}$	58 079.07	−44(3)	473(58)	8 167

Table 7. Energy, quantum numbers and hyperfine constants of the newly discovered tantalum energy levels with odd parity.

config.	des.	energy /cm^{-1}	A/MHz	B/MHz	line(s) under study /Å
$5d^36s(^5\mathrm{F})6p$	$^6\mathrm{G}_{13/2}$	27 778.09	1 020.4(10)	1 431(12)	5 115
	$?_{1/2}$	33 561.28	2 802.1(5)	0	3 633
	$?_{1/2}$	35 071.36	661.1(5)	0	7 788
	$?_{13/2}$	36 130.32	1 121.2(20)	2 059(60)	7 296
	$?_{9/2}$	41 641.97	−138(1)	703(24)	7 981
$5d^36s(^3\mathrm{H})6p$	$^4\mathrm{I}_{15/2}$	41 724.35	1 025.2(5)	7 152(8)	5 490, 8 940
	$?_{9/2}$	47 160.34	345.4(5)	23(10)	7 092
	$?_{9/2}$	47 621.80	193(8)	1 640(230)	6 479
	$?_{5/2}$	48 537.97	106(3)	−502(42)	8 437
	$?_{11/2}$	49 682.23	718.1(15)	4 325(45)	4 953
	$?_{1/2}$	55 812.93	−1 496(8)	0	8 532

Since several earlier attempts to excite an allowed combination of the even parity energy level $T = 47\,817.16\,\mathrm{cm}^{-1}$, $J = 7/2$, with another already established odd parity energy level had been unsuccessful, in [6] this level erroneously was believed not to exist. The discovery of the new line $\lambda_{\mathrm{air}} = 6\,981.306$ Å during this work (see Tab. 1) fortunately revealed this error. The hfs-constants of this level have been included in Table 4.

After the first parametric studies of the $5d^36s7s$ configuration [22] we assume that none of the $e\ ^4\mathrm{F}$ levels given in [16] are correctly assigned. In the meantime we have discovered two new even levels at $43\,275.47$ cm^{-1}, $J = 3/2$ and $44\,918.67$ cm^{-1}, $J = 5/2$ (see Tab. 6) both probably belonging to the $e\ ^4\mathrm{F}$ term (this can be inferred from comparison of measured and expected A- and B-values). Accordingly, the $J = 7/2$ and $9/2$ levels of the $e\ ^4\mathrm{F}$ term are still to be found.

Although four levels are used during our experimental investigation their details will be published in forthcoming papers. This concerns the energy levels $27\,778.09_{13/2}$ cm^{-1} [23], $32\,187.39_{3/2}$ cm^{-1} [24] and $29\,116.26_{9/2}$ cm^{-1}, $30\,542.35_{13/2}$ cm^{-1} [25].

4 Conclusion

Although a lot of work has been done in recent years, many problems concerning the fine- and hyperfine structure of the atomic tantalum spectrum are still unresolved. Especially for the odd parity level subsystem, no successful fine structure analysis could be performed in the past. In order to achieve such an analysis, experimental data is of special interest. Moreover, a detailed theoretical analysis of the high lying even parity levels would be useful. Nevertheless, owing to the Poznań-Graz-Hamburg cooperation the collection of Ta I hyperfine structure data are amongst the most comprehensive of all complex spectra investigated up to now. Further laser-spectroscopic research on Ta I is in progress.

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