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New Even Levels and Classified Lines in the First Spectrum of Tungsten (W I)

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Ten new even levels, which classify 161 previously unclassified lines, have been found in the first spectrum of tungsten. Nine of these fit levels in the $(5d+6s)^6$ mixture of configurations calculated theoretically by Shadmi and Caspi.

Key words: Atomic energy levels in W I; classified lines of W I; spectrum, W I; tungsten, first spectrum; W I.

Recently Laun and Corliss [1968] published an extensive list of levels and classified lines for the first spectrum of tungsten (W I). Prompted by these experimental data, Shadmi and Caspi [1968] published a theoretical interpretation of the low even levels arising from the $(5d+6s)^6$ mixture of configurations. Their work provided an interpretation for every level found experimentally below 40000 cm^{-1} and predicted values for numerous levels not yet found. It seemed worthwhile to search for some of these levels.

The search has been made with the Combo program for finding energy levels, which was developed by J. L. Tech in the National Bureau of Standards Spectroscopy Section. With this program, the wavenumbers of 1391 unclassified W I lines were used to search for new even levels in the energy region where levels were predicted to lie. Ten new levels with numbers of combinations significantly above the noise were found. (The noise level in this case was about 6 to 8 combinations for fortuitous levels.) The new levels, which have J-values 2, 3, 4, and 5 are marked with asterisks (*) in table 1.

The previously known levels with J-values from 1 through 5 are also listed in order to show the remarkable regularity in the relationship between the number of combinations (N) made by each level and the level value. According to Shadmi and Caspi, the three levels marked in parentheses seem of doubtful reality, in view of the relatively large differences between the observed and calculated values for these levels. However, the tabulations in table 1 show that the number of combinations made by these three levels in question is about the number to be expected. Furthermore, since that number is about five times above the noise level number, it is likely that the levels are indeed real.

TABLE 1. *Even levels in* W I.

Number of combinations	J	Observed level (cm^{-1})	Calculated level (cm^{-1})	Difference O–C (cm^{-1})
87	1	1670.29	1697	−27
103	1	13307.10	13405	−98
84	1	18082.83	18095	−12
78	1	20427.84	20407	21
58	1	23455.02	23541	−86
34	1	(27670.48)	28123	(−453)
24	1	28720.88	28877	−156
15	1	32378.40	32443	−65
128	2	3325.53	3382	−57
144	2	13777.71	13708	70
149	2	14976.18	15058	−82
131	2	18116.84	18240	−123
132	2	18280.48	18385	−105
130	2	19253.56	19283	−30
110	2	20983.02	21031	−48
77	2	23982.80	24028	−45
57	2	24789.66	24799	−9
61	2	26861.64	26844	18
44	2	(28204.20)	28576	(−372)
34	2	28898.96	28790	109
30	2	(30374.20)	29840	(534)
18	2	*31077.79	31037	41
107	3	2951.29	2833	118
145	3	4830.00	4836	−6
173	3	13348.56	13424	−76
173	3	15460.01	15405	55
154	3	17701.18	17736	−35
152	3	18974.51	18994	−20
154	3	19827.68	19759	69
114	3	23930.08	23870	60
85	3	24610.88	24741	−130
62	3	28291.88	28196	96
54	3	28347.60	28454	−106
26	3	*29430.50	29409	21
17	3	*32217.95	31996	222

TABLE 1. *Even levels in* W I. — Continued

Number of combinations	J	Observed level (cm^{-1})	Calculated level (cm^{-1})	Difference O–C (cm^{-1})	Number of combinations	J	Observed level (cm^{-1})	Calculated level (cm^{-1})	Difference O–C (cm^{-1})
13	3	*32826.63	32821	6	50	4	29853.66	29813	41
11	3	*33952.85	33675	278	31	4	32135.94	31902	234
10	3	*34465.83	34566	−100	17	4	*33569.53	33421	149
10	3	*37414.11	37143	271	26	4	34302.04	34159	143
					14	4	*35299.82	35219	81
133	4	6219.33	6105	114					
159	4	12161.96	12162	0	123	5	15069.93	15124	−54
144	4	16431.31	16567	−136	115	5	19535.01	19391	144
153	4	17107.01	17043	64	115	5	19826.04	20035	−209
138	4	19256.24	19275	−19	68	5	27849.80	27755	95
117	4	22476.68	22442	35	67	5	28233.44	28273	−40
99	4	22852.80	22826	27	49	5	31389.08	31256	133
81	4	27213.82	27114	100	20	5	*33201.61	.....	.....
48	4	29479.32	29453	26	28	5	33291.80	33352	−60

TABLE 2. — *Newly Classified Lines of* W I

Wavelength Å	Intensity	Wavenumber (cm^{-1}) Observed	Wavenumber (cm^{-1}) O–C	Classification (levels in cm^{-1})	Wavelength Å	Intensity	Wavenumber (cm^{-1}) Observed	Wavenumber (cm^{-1}) O–C	Classification (levels in cm^{-1})
3113.876	8	32105.01	0.01	29430_3–61535°_4	4736.036	3	21108.80	0.11	33201_5–54310°_5
3523.446	3	28373.19	0.03	29430_3–57803°_4	4809.642	3	20785.76	−0.05	32217_3–53003°_2
3578.011	2	27940.51	0.10	32217_3–60158°_4	4865.33	3	20547.85	0.02	33569_4–54117°_3
3580.40	2	27921.87	0.05	29430_3–57352°_3	5019.52	3	19916.67	−0.01	33201_5–53118°_4
3608.904	4	27701.34	0.06	29430_3–57131°_3	5023.423	2*b*	19901.19	0.05	37414_3–57315°_4
3625.059	2	27577.90	−0.04	31077_2–58655°_2	5044.908	4	19816.44	0.11	31077_2–50894°_3
3627.611	2	27558.50	0.04	32826_3–60385°_4	5094.173	6	19624.80	0.08	33569_4–53194°_5
3726.776	2	26825.22	0.07	29430_3–56255°_4	5107.78	5	19572.52	0.03	33201_5–52774°_5
3749.935	2	26659.55	−0.10	33569_4–60229°_5	5133.11	20	19475.94	0.00	32217_3–51693°_2
3918.195	2	25514.73	0.18	32217_3–57732°_3	5145.453	8	19429.22	0.05	32826_3–52255°_3
3931.44	2	25428.77	0.12	29430_3–54859°_2	5282.646	4*b*	18924.64	0.05	34465_3–53390°_3
3978.822	2	25125.96	0.03	29430_3–54556°_3	5295.252	6	18879.59	0.11	33201_5–52081°_5
4005.893	8	24956.17	0.00	34465_3–59422°_2	5295.252	6	18879.59	−0.10	34465_3–53345°_3
4012.704	1	24913.81	−0.06	32217_3–57131°_3	5310.37	4	18825.84	−0.13	33569_4–52395°_5
4048.854	5	24691.37	0.12	33952_3–58644°_3	5312.282	5	18819.07	0.11	35299_4–54118°_4
4062.26	1	24609.89	0.04	33569_4–58179°_5	5312.282	5	18819.07	−0.02	34465_3–53284°_2
4101.648	3	24373.57	0.07	35299_4–59673°_5	5345.887	3*b*	18700.77	0.04	33952_3–52653°_2
4116.718	3	24284.34	0.15	32217_3–56502°_4	5389.661	3	18548.88	0.08	35299_4–53848°_4
4158.954	2	24037.73	−0.01	32217_3–56255°_4	5392.78	4	18538.16	0.04	29430_3–47968°_4
4167.002	2*b*	23991.30	0.01	33569_4–57560°_5	5443.35	12	18365.94	0.02	31077_2–49443°_1
4240.913	3	23573.19	−0.03	29430_3–53003°_2	5469.932	2	18276.68	0.05	32217_3–50494°_2
4257.978	3	23478.72	0.08	31077_2–54556°_3	5471.50	3	18271.45	0.02	33201_5–51473°_4
4262.267	4	23455.09	0.09	29430_3–52885°_2	5479.229	10	18245.67	0.17	32826_3–51072°_3
4282.922	1	23341.98	0.10	31077_2–54419°_1	5495.256	3	18192.46	0.09	31077_2–49270°_2
4290.53	2	23300.59	0.10	33201_5–56502°_4	5526.644	2*b*	18089.14	0.02	33201_5–51290°_5
4314.424	2	23171.55	0.16	32217_3–55389°_3	5539.91	2	18045.82	0.12	35299_4–53345°_3
4352.11	2*b*	22970.90	−0.08	37414_3–60385°_4	5550.319	4	18011.98	−0.05	29430_3–47442°_2
4359.37	2	22932.65	0.08	33569_4–56502°_4	5563.97	4*b*	17967.79	0.00	32217_3–50185°_3
4364.40	3	22906.22	0.04	35299_4–58206°_3	5641.39	5	17721.21	0.01	33569_4–51290°_5
4381.862	5	22814.94	0.18	32217_3–55032°_2	5721.10	2	17474.31	0.03	35299_4–52774°_5
4509.30	4*b*	22170.17	0.15	29430_3–51600°_3	5726.43	2	17458.04	0.03	32826_3–50284°_4
4535.389	2	22042.64	0.10	29430_3–51473°_4	5803.04	3	17227.57	0.00	33201_5–50429°_6
4584.244	3	21807.74	0.03	31077_2–52885°_2	5848.81	2	17092.76	0.00	31077_2–48170°_3
4731.027	2	21131.15	−0.02	33952_3–55084°_2	5905.05	4	16929.97	−0.07	32217_3–49147°_4
4731.027	2	21131.15	0.08	34465_3–55596°_4	5931.13	2	16855.52	−0.14	37414_3–54269°_3

TABLE 2.—*Newly Classified Lines of* W I—Continued

Wavelength Å	Intensity	Wavenumber (cm^{-1}) Observed	O–C	Classification (levels in cm^{-1})	Wavelength Å	Intensity	Wavenumber (cm^{-1}) Observed	O–C	Classification (levels in cm^{-1})
5980.95	2	16715.12	0.01	33569_4–50284°_4	7245.88	1	13797.14	−0.02	29430_3–43227°_2
6053.17	2*b*	16515.70	0.05	31077_2–47593°_3	7318.95	1	13659.40	−0.02	31077_2–44737°_1
6082.89	3	16435.00	0.09	33201_5–49636°_4	7416.29	1	13480.12	−0.12	29430_3–42910°_4
6179.66	3	16177.64	−0.12	31077_2–47255°_1	7416.29	1	13480.12	0.11	37414_3–50894°_3
6181.39	2	16173.12	−0.10	35299_4–51473°_4	7473.90	1	13376.21	−0.05	35299_4–48676°_4
6243.10	2	16013.25	0.07	33952_3–49966°_3	7590.55	1	13170.65	−0.04	29430_3–42601°_3
6251.48	5	15991.79	0.03	29430_3–45422°_2	7641.04	3	13083.62	−0.02	29430_3–42514°_3
6253.63	6	15986.29	−0.02	33201_5–49187°_5	7678.57	6	13019.68	−0.06	29430_3–42450°_4
6269.28	4	15946.38	0.04	33201_5–49147°_4	7680.12	1	13017.05	−0.02	21448°_2–34465_3
6298.57	6	15872.23	−0.04	33201_5–49073°_5	7702.63	2*b*	12979.01	0.02	33952_3–46931°_4
6415.03	1	15584.08	0.04	29430_3–45014°_3	7704.00	1*b*	12976.70	0.00	34465_3–47442°_2
6417.36	4	15578.43	0.01	33569_4–49147°_4	7747.07	3	12904.56	−0.04	33201_5–46106°_6
6447.25	1	15506.20	−0.05	35299_4–50806°_5	7797.57	5	12820.98	−0.03	29430_3–42251°_3
6448.76	1	15502.57	−0.04	33569_4–49072°_3	7812.44	7	12796.58	−0.05	32217_3–45014°_3
6449.93	3	15499.76	−0.02	32826_3–48326°_3	7826.86	3	12773.00	−0.05	31077_2–43850°_3
6461.78	5	15471.34	−0.08	32217_3–47689°_4	7967.14	20	12548.10	−0.02	29430_3–41978°_2
6461.78	5	15471.34	−0.05	37414_3–52885°_2	7998.74	2	12498.53	0.04	33569_4–46068°_3
6464.43	4	15464.99	−0.06	33952_3–49417°_3	8039.04	1	12435.88	−0.04	32826_3–45262°_4
6515.44	3	15343.92	−0.01	32826_3–48170°_3	8061.78	2*b*	12400.80	0.01	31077_2–43478°_3
6602.37	1	15141.89	−0.10	32826_3–47968°_4	8076.41	2	12378.34	−0.03	32217_3–44596°_2
6612.24	2	15119.29	0.00	33952_3–49072°_3	8101.05	1	12340.68	0.06	34465_3–46806°_2
6652.98	1	15026.71	−0.12	31077_2–46104°_1	8125.47	10	12303.60	−0.03	29430_3–41734°_2
6669.22	2	14990.12	−0.11	31077_2–46068°_3	8137.38	8	12285.59	0.14	37414_3–49699°_2
6671.59	1	14984.79	−0.03	35299_4–50284°_4	8151.80	1	12263.86	0.02	29430_3–41694°_3
6726.42	4	14862.65	−0.06	32826_3–47689°_4	8161.04	1	12249.97	−0.07	33201_5–45451°_5
6770.04	8	14766.89	0.08	32826_3–47593°_3	8175.02	1	12229.02	−0.09	32217_3–44447°_3
6846.90	1	14601.12	0.10	33569_4–48170°_3	8181.34	1	12219.58	−0.03	33569_4–45789°_5
6846.90	1	14601.12	−0.05	37414_3–52015°_3	8251.89	1	12115.11	−0.06	33952_3–46068°_3
6852.84	2	14588.46	−0.08	32217_3–46806°_2	8283.50	2	12068.87	−0.06	29430_3–41499°_3
6862.07	5	14568.84	−0.01	33569_4–48138°_5	8289.01	1	12060.85	−0.09	33201_5–45262°_4
6900.54	12	14487.62	−0.10	33201_5–47689°_4	8390.39	10	11915.12	−0.04	33201_5–45116°_4
6971.64	15	14339.87	−0.08	33201_5–47541°_6	8428.10	1	11861.81	−0.11	34465_3–46327°_2
6992.96	10	14296.15	−0.06	31077_2–45374°_1	8470.08	4	11803.02	−0.07	32217_3–44021°_3
7031.56	2	14217.67	−0.03	33952_3–48170°_3	8495.70	8	11767.43	−0.07	32217_3–43985°_4
7033.14	2	14214.48	−0.04	35299_4–49514°_3	8619.49	2	11598.43	−0.04	33952_3–45551°_3
7043.94	4*b*	14192.69	0.02	37414_3–51606°_2	8651.92	1	11554.95	−0.03	35299_4–46854°_5
7060.86	5	14158.68	0.10	33201_5–47360°_4	8662.53	1	11540.80	−0.07	32826_3–44367°_2
7081.21	1	14117.99	−0.09	35299_4–49417°_3	8691.03	1*b*	11502.96	0.00	32217_3–43720°_4
7098.22	15	14084.15	−0.03	29430_3–43514°_2	8698.35	8	11493.28	−0.05	29430_3–40923°_3
7128.71	2	14023.92	0.01	33569_4–47593°_3	8791.89	1	11371.00	−0.04	33569_4–44940°_4
7132.89	1	14015.70	−0.07	33952_3–47968°_4	8947.10	1	11173.74	0.02	31077_2–42251°_3
7151.20	1	13979.81	−0.01	32826_3–46806°_2	9018.33	1	11085.48	−0.01	34465_3–45551°_3
7173.38	5*b*	13936.59	−0.17	31077_2–45014°_3	9270.69	1	10783.72	−0.08	33201_5–43985°_4
7218.22	6*b*	13850.01	−0.10	32217_3–46068°_3	9353.72	2	10688.00	−0.05	32826_3–43514°_2
7219.18	2	13848.17	0.04	35299_4–49147°_4	9928.10	5	10069.66	0.09	37414_3–47483°_3
					9968.85	2	10028.50	0.08	37414_3–47442°_2

The new level at 33201.61 ($J=5$) has no place in the $(5d+6s)^6$ theoretical scheme as given by Shadmi and Caspi. Since it makes 20 combinations (3 times above the noise level) it is probably real.

The lines classified by these new levels are listed in table 2. The line at 7098 Å was inadvertently omitted from table 3 of Laun and Corliss [1968].

References

Laun, Donald D. and Corliss, C. H. (1968), J. Res. NBS **72A** (Phys. and Chem.) No. 6, 609 (1968).

Shadmi, Y. and Caspi, E. (1968), J. Res. NBS **72A** (Phys. and Chem.) No. 6, 757 (1968).

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