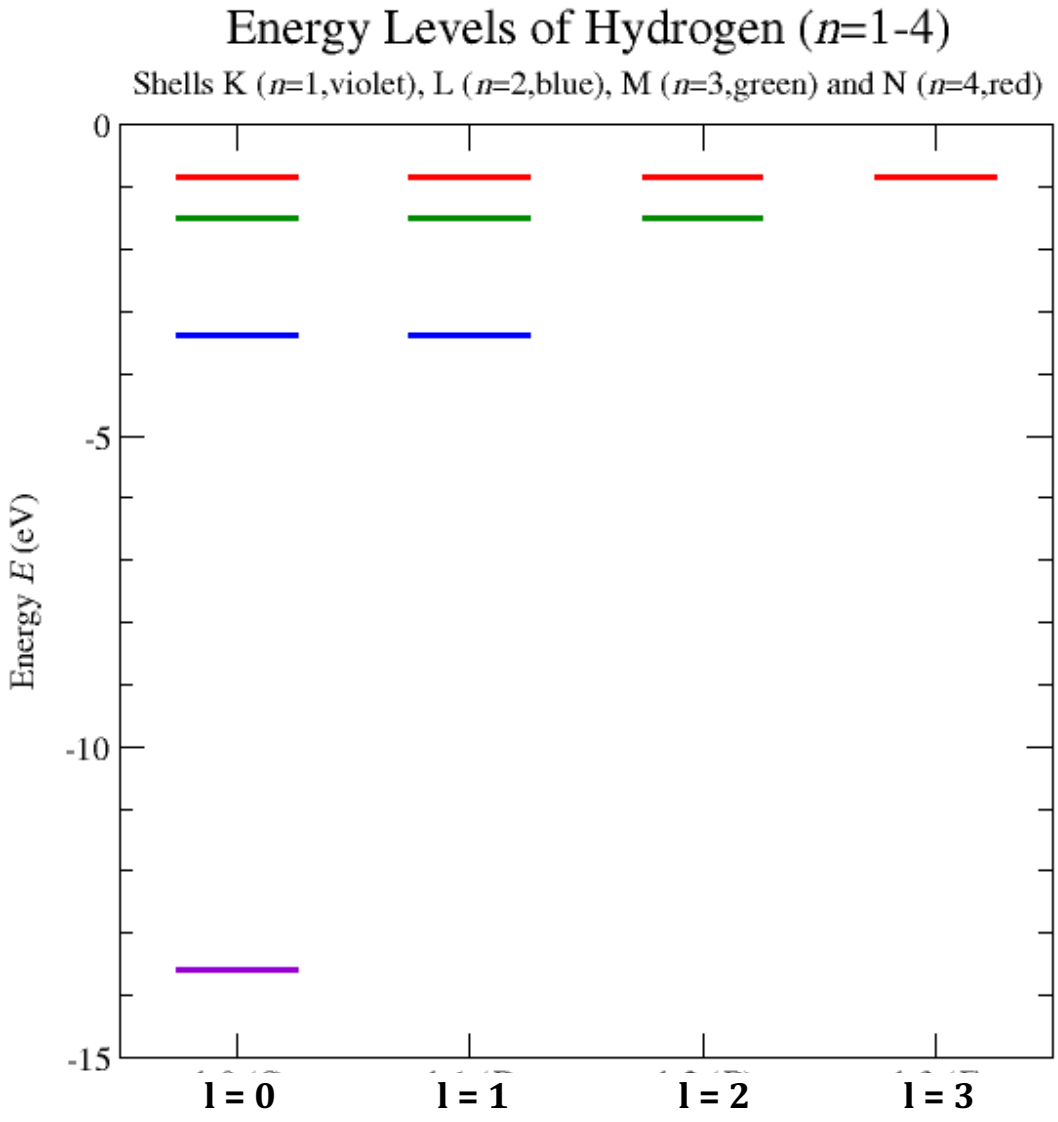
AST 300B – Spring 2019

In-class/Take-home Problems Due: Wed. Mar. 13

23. An electron recombines into a (nl = 4d) state of Hydrogen. What are the probabilities for the allowed electric dipole radiative transitions starting from the 4d level? Continue the allowed radiative cascade until you are stuck (cannot radiate via electric dipole rules) or are in the ground state. Give the names (i.e Ly γ) for each of the allowed transitions in the radiative cascade and the probability that you will get a photon through that transition. This is a "branching ratio" calculation.

Redraw this diagram on the board:



HYDROGEN

H

Ground State $1s\ ^2S_{1/2}$

Ionization Potential $13.595\ \text{eV} = 109678.758\ \text{cm}^{-1}$

Allowed Transitions

For hydrogen a special tabular arrangement is used. In Table A the "average" transition probabilities for transitions between lower states of principal quantum number $(n)_i$ to upper states $(n)_k$ are listed. They are taken from extensive calculations by Green, Rush, and Chandler; Harriman; Herdan and Hughes; Karzas and Latter; and Menzel and Pekeris [1]. These values are applicable to most problems in plasma spectroscopy and astrophysics (see general introduction, Sec. E). Table B contains the probabilities for transitions between the various sublevels $(nl)_i - (nl)_k$. This table should be useful primarily for theoretical applications. Both tables include only four significant figures since relativistic effects, which are of the order of α^2, have been neglected in the calculations (α is the fine structure constant). It should be noted that Green, Rush, and Chandler; and Harriman list more transitions, but these, not being of any practical importance, are omitted.

Table C contains the values for nine fine structure lines as calculated from the work of Wild [2]. The effect of the Lamb shift has been taken into account by using his equation (4a) to calculate the line strength and then by using the energy levels given in NBS Circular 467 (Atomic Energy Levels) for conversion into the other quantities.

The values for the transition between the two hyperfine structure components of the $1s\ ^2S_{1/2}$ level are also taken from Wild [2] and are given in Table D. This magnetic dipole transition has a statistical weight of $2f+1$, where f is $j \pm 1/2$ for hydrogen.

The metastable $2s\ ^2S_{1/2}$ level gives rise to transitions to the ground state only by means of two-photon emission. This process was studied in particular by Shapiro and Breit [3]. Their calculation of the transition probability for the $1s\ ^2S_{1/2} - 2s\ ^2S_{1/2}$ transition gives a value of $8.23\ \text{sec}^{-1}$ with an estimated accuracy of better than 3 percent. The transition itself gives rise to a continuum; hence no f or S values are given.

Finally, it should be mentioned that in the conversion factors used for hydrogen the reduced mass and other appropriate constants are taken into account.

References

[1] Green, L. C., Rush, P. P., and Chandler, C. D., Astrophys. J. Suppl. Ser. **3,** 37–50 (1957); Harriman, J. M., Phys. Rev. **101,** 594–598 (1956) and Document No. 4705, American Documentation Institute Auxiliary Publications Project, Photoduplication Service, Library of Congress, Washington, D. C.; Herdan, R., and Hughes, T. P., Astrophys. J. **133,** 294–298 (1961); Karzas, W. J., and Latter, R., Astrophys. J. Suppl. Ser. **6,** 167–212 (1961); Menzel, D. H., and Pekeris, C. L., Monthly Notices Roy. Astron. Soc. **96,** 77–111 (1935).

[2] Wild, J. P., Astrophys. J. **115,** 206–221 (1952).

[3] Shapiro, J., and Breit, G., Phys. Rev. **113,** 179–181 (1959).

H—Table A. $(n)_i - (n)_k$ Transitions (Average Values)

Transition	λ(Å)	E_i(cm^{-1})	E_k(cm^{-1})	g_i	g_k	A_{ki}(sec^{-1})	f_{ik}	S(at.u.)	log gf	Accuracy	Source
1—2 (L_α)	1215.67	0	82259	2	8	4.699×10^{8}	0.4162	3.330	−0.0797	AA	1
1—3 (L_β)	1025.72	0	97492	2	18	5.575×10^{7}	7.910×10^{-2}	0.5339	−0.8008	AA	1
1—4 (L_γ)	792.537	0	102824	2	32	1.278×10^{7}	2.899×10^{-2}	0.1855	−1.2367	AA	1
1—5 (L_δ)	949.743	0	105292	2	50	4.125×10^{6}	1.394×10^{-2}	8.711×10^{-2}	−1.5548	AA	1
1—6 (L_ϵ)	937.803	0	106632	2	72	1.644×10^{6}	7.799×10^{-3}	4.813×10^{-2}	−1.8069	AA	1
1—7	930.748	0	107440	2	98	7.568×10^{5}	4.814×10^{-3}	2.948×10^{-2}	−2.0165	AA	1
1—8	926.226	0	107965	2	128	3.869×10^{5}	3.183×10^{-3}	1.940×10^{-2}	−2.1961	AA	1
1—9	923.150	0	108325	2	162	2.143×10^{5}	2.216×10^{-3}	1.346×10^{-2}	−2.3534	AA	1
1—10	920.963	0	108582	2	200	1.263×10^{5}	1.605×10^{-3}	9.729×10^{-3}	−2.4934	AA	1
1—11	919.352	0	108772	2	242	7.834×10^{4}	1.201×10^{-3}	7.263×10^{-3}	−2.6196	AA	1
1—12	918.129	0	108917	2	288	5.066×10^{4}	9.214×10^{-4}	5.567×10^{-3}	−2.7345	AA	1
1—13	917.181	0	109030	2	338	3.393×10^{4}	7.227×10^{-4}	4.362×10^{-3}	−2.8400	AA	1
1—14	916.429	0	109119	2	392	2.341×10^{4}	5.774×10^{-4}	3.482×10^{-3}	−2.9375	AA	1
1—15	915.824	0	109191	2	450	1.657×10^{4}	4.686×10^{-4}	2.824×10^{-3}	−3.0281	AA	1
1—16	915.329	0	109250	2	512	1.200×10^{4}	3.856×10^{-4}	2.323×10^{-3}	−3.1129	AA	1
1—17	914.919	0	109299	2	578	8858	3.211×10^{-4}	1.933×10^{-3}	−3.1924	AA	1
1—18	914.576	0	109340	2	648	6654	2.702×10^{-4}	1.626×10^{-3}	−3.2673	AA	1
1—19	914.286	0	109375	2	722	5077	2.296×10^{-4}	1.381×10^{-3}	−3.3381	AA	1
1—20	914.039	0	109405	2	800	3928	1.967×10^{-4}	1.183×10^{-3}	−3.4052	AA	1
1—21	913.826	0	109430	2	882	3077	1.698×10^{-4}	1.021×10^{-3}	−3.4691	AA	1
1—22	913.641	0	109452	2	968	2438	1.476×10^{-4}	8.874×10^{-4}	−3.5299	AA	1
1—23	913.480	0	109471	2	1058	1952	1.291×10^{-4}	7.761×10^{-4}	−3.5880	AA	1
1—24	913.339	0	109488	2	1152	1578	1.136×10^{-4}	6.827×10^{-4}	−3.6436	AA	1
1—25	913.215	0	109503	2	1250	1286	1.005×10^{-4}	6.037×10^{-4}	−3.6970	AA	1
1—26	913.104	0	109517	2	1352	1057	8.928×10^{-5}	5.364×10^{-4}	−3.7482	AA	1
1—27	913.006	0	109528	2	1458	875.3	7.970×10^{-5}	4.788×10^{-4}	−3.7975	AA	1
1—28	912.918	0	109539	2	1568	729.7	7.144×10^{-5}	4.292×10^{-4}	−3.8450	AA	1
1—29	912.839	0	109548	2	1682	612.2	6.429×10^{-5}	3.862×10^{-4}	−3.8908	AA	1
1—30	912.768	0	109557	2	1800	516.7	5.806×10^{-5}	3.487×10^{-4}	−3.9351	AA	1
1—31	912.703	0	109565	2	1922	438.6	5.261×10^{-5}	3.160×10^{-4}	−3.9779	AA	1
1—32	912.645	0	109572	2	2048	374.2	4.782×10^{-5}	2.872×10^{-4}	−4.0193	AA	1
1—33	912.592	0	109578	2	2178	320.8	4.360×10^{-5}	2.618×10^{-4}	−4.0595	AA	1
1—34	912.543	0	109584	2	2312	276.3	3.986×10^{-5}	2.394×10^{-4}	−4.0985	AA	1
1—35	912.499	0	109589	2	2450	239.0	3.653×10^{-5}	2.194×10^{-4}	−4.1363	AA	1
1—36	912.458	0	109594	2	2592	207.6	3.357×10^{-5}	2.016×10^{-4}	−4.1730	AA	1
1—37	912.420	0	109599	2	2738	181.0	3.092×10^{-5}	1.856×10^{-4}	−4.2088	AA	1
1—38	912.385	0	109603	2	2888	158.4	2.854×10^{-5}	1.713×10^{-4}	−4.2436	AA	1
1—39	912.353	0	109607	2	3042	139.1	2.640×10^{-5}	1.585×10^{-4}	−4.2774	AA	1
1—40	912.324	0	109610	2	3200	122.6	2.446×10^{-5}	1.469×10^{-4}	−4.3105	AA	1
2—3 (H_α)	6562.80	82259	97492	8	18	4.410×10^{7}	0.6407	110.7	0.7098	AA	1
2—4 (H_β)	4861.32	82259	102824	8	32	8.419×10^{6}	0.1193	15.27	−0.0202	AA	1
2—5 (H_λ)	4340.46	82259	105292	8	50	2.530×10^{6}	4.467×10^{-2}	5.105	−0.4469	AA	1
2—6 (H_δ)	4101.73	82259	106632	8	72	9.732×10^{5}	2.209×10^{-2}	2.386	−0.7527	AA	1
2—7 (H_ϵ)	3970.07	82259	107440	8	98	4.389×10^{5}	1.270×10^{-2}	1.328	−0.9929	AA	1
2—8	3889.05	82259	107965	8	128	2.215×10^{5}	8.036×10^{-3}	0.8228	−1.1919	AA	1
2—9	3835.38	82259	108325	8	162	1.216×10^{5}	5.429×10^{-3}	0.5482	−1.3622	AA	1
2—10	3797.90	82259	108582	8	200	7.122×10^{4}	3.851×10^{-3}	0.3851	−1.5114	AA	1
2—11	3770.63	82259	108772	8	242	4.397×10^{4}	2.835×10^{-3}	0.2815	−1.6443	AA	1
2—12	3750.15	82259	108917	8	288	2.834×10^{4}	2.151×10^{-3}	0.2124	−1.7643	AA	1
2—13	3734.37	82259	109030	8	338	1.893×10^{4}	1.672×10^{-3}	0.1644	−1.8737	AA	1
2—14	3721.94	82259	109119	8	392	1.303×10^{4}	1.326×10^{-3}	0.1300	−1.9743	AA	1
2—15	3711.97	82259	109191	8	450	9210	1.070×10^{-3}	0.1046	−2.0674	AA	1
2—16	3703.85	82259	109250	8	512	6658	8.764×10^{-4}	8.547×10^{-2}	−2.1542	AA	1
2—17	3697.15	82259	109299	8	578	4910	7.270×10^{-4}	7.077×10^{-2}	−2.2354	AA	1

H—Table A. $(n)_i - (n)_k$ Transitions (Average Values)—*Continued*

Transition	λ(Å)	E_i(cm^{-1})	E_k(cm^{-1})	g_i	g_k	A_{ki}(sec^{-1})	f_{ik}	S(at.u.)	log gf	Accuracy	Source
2−18	3691.55	82259	109340	8	648	3685	6.099×10^{-4}	5.928×10^{-2}	−2.3117	AA	1
2−19	3686.83	82259	109375	8	722	2809	5.167×10^{-4}	5.016×10^{-2}	−2.3837	AA	1
2−20	3682.81	82259	109405	8	800	2172	4.416×10^{-4}	4.283×10^{-2}	−2.4518	AA	1
2−21	3679.35	82259	109430	8	882	1700	3.805×10^{-4}	3.686×10^{-2}	−2.5165	AA	1
2−22	3676.36	82259	109452	8	968	1347	3.302×10^{-4}	3.196×10^{-2}	−2.5781	AA	1
2−23	3673.76	82259	109471	8	1058	1078	2.884×10^{-4}	2.790×10^{-2}	−2.6369	AA	1
2−24	3671.48	82259	109488	8	1152	870.7	2.534×10^{-4}	2.449×10^{-2}	−2.6931	AA	1
2−25	3669.46	82259	109503	8	1250	709.6	2.238×10^{-4}	2.163×10^{-2}	−2.7470	AA	1
2−26	3667.68	82259	109517	8	1352	583.0	1.987×10^{-4}	1.919×10^{-2}	−2.7987	AA	1
2−27	3666.10	82259	109528	8	1458	482.6	1.772×10^{-4}	1.711×10^{-2}	−2.8484	AA	1
2−28	3664.68	82259	109539	8	1568	402.2	1.587×10^{-4}	1.532×10^{-2}	−2.8962	AA	1
2−29	3663.40	82259	109548	8	1682	337.4	1.427×10^{-4}	1.377×10^{-2}	−2.9424	AA	1
2−30	3662.26	82259	109557	8	1800	284.7	1.288×10^{-4}	1.242×10^{-2}	−2.9869	AA	1
2−31	3661.22	82259	109565	8	1922	241.6	1.167×10^{-4}	1.125×10^{-2}	−3.0300	AA	1
2−32	3660.28	82259	109572	8	2048	206.1	1.060×10^{-4}	1.021×10^{-2}	−3.0717	AA	1
2−33	3659.42	82259	109578	8	2178	176.7	9.658×10^{-5}	9.305×10^{-3}	−3.1120	AA	1
2−34	3658.64	82259	109584	8	2312	152.2	8.825×10^{-5}	8.501×10^{-3}	−3.1512	AA	1
2−35	3657.92	82259	109589	8	2450	131.6	8.086×10^{-5}	7.788×10^{-3}	−3.1892	AA	1
2−36	3657.27	82259	109594	8	2592	114.3	7.427×10^{-5}	7.152×10^{-3}	−3.2261	AA	1
2−37	3656.66	82259	109599	8	2738	99.66	6.837×10^{-5}	6.583×10^{-3}	−3.2620	AA	1
2−38	3656.11	82259	109603	8	2888	87.20	6.309×10^{-5}	6.073×10^{-3}	−3.2969	AA	1
2−39	3655.59	82259	109607	8	3042	76.57	5.834×10^{-5}	5.615×10^{-3}	−3.3310	AA	1
2−40	3655.12	82259	109610	8	3200	67.46	5.405×10^{-5}	5.202×10^{-3}	−3.3641	AA	1
3−4 (P_α)	18751.0	97492	102824	18	32	8.986×10^{6}	0.8421	935.4	1.1806	AA	1
3−5 (P_β)	12818.1	97492	105292	18	50	2.201×10^{6}	0.1506	114.3	0.4331	AA	1
3−6 (P_γ)	10938.1	97492	106632	18	72	7.783×10^{5}	5.584×10^{-2}	36.18	0.0022	AA	1
3−7 (P_δ)	10049.4	97492	107440	18	98	3.358×10^{5}	2.768×10^{-2}	16.48	−0.3025	AA	1
3−8 (P_ϵ)	9545.98	97492	107965	18	128	1.651×10^{5}	1.604×10^{-2}	9.069	−0.5396	AA	1
3−9	9229.02	97492	108325	18	162	8.905×10^{4}	1.023×10^{-2}	5.595	−0.7347	AA	1
3−10	9014.91	97492	108582	18	200	5.156×10^{4}	6.980×10^{-3}	3.728	−0.9009	AA	1
3−11	8862.79	97492	108772	18	242	3.156×10^{4}	4.996×10^{-3}	2.623	−1.0461	AA	1
3−12	8750.47	97492	108917	18	288	2.021×10^{4}	3.711×10^{-3}	1.924	−1.1752	AA	1
3−13	8665.02	97492	109030	18	338	1.343×10^{4}	2.839×10^{-3}	1.457	−1.2916	AA	1
3−14	8598.39	97492	109119	18	392	9211	2.224×10^{-3}	1.133	−1.3977	AA	1
3−15	8545.39	97492	109191	18	450	6490	1.776×10^{-3}	0.8992	−1.4952	AA	1
3−16	8502.49	97492	109250	18	512	4680	1.443×10^{-3}	0.7267	−1.5855	AA	1
3−17	8467.26	97492	109299	18	578	3444	1.188×10^{-3}	0.5963	−1.6696	AA	1
3−18	8437.96	97492	109340	18	648	2580	9.916×10^{-4}	0.4957	−1.7484	AA	1
3−19	8413.32	97492	109375	18	722	1964	8.361×10^{-4}	0.4167	−1.8225	AA	1
3−20	8392.40	97492	109405	18	800	1517	7.118×10^{-4}	0.3539	−1.8924	AA	1
4−5	40512.0	102824	105292	32	50	2.699×10^{6}	1.038	4428	1.5212	AA	1
4−6	26252.0	102824	106632	32	72	7.711×10^{5}	0.1793	495.6	0.7586	AA	1
4−7	21655.0	102824	107440	32	98	3.041×10^{5}	6.549×10^{-2}	149.4	0.3213	AA	1
4−8	19445.6	102824	107965	32	128	1.424×10^{5}	3.230×10^{-2}	66.14	0.0143	AA	1
4−9	18174.1	102824	108325	32	162	7.459×10^{4}	1.870×10^{-2}	35.79	−0.2230	AA	1
4−10	17362.1	102824	108582	32	200	4.235×10^{4}	1.196×10^{-2}	21.87	−0.4171	AA	1
4−11	16806.5	102824	108772	32	242	2.556×10^{4}	8.187×10^{-3}	14.49	−0.5817	AA	1
4−12	16407.2	102824	108917	32	288	1.620×10^{4}	5.886×10^{-3}	10.17	−0.7250	AA	1
4−13	16109.3	102824	109030	32	338	1.069×10^{4}	4.393×10^{-3}	7.452	−0.8521	AA	1
4−14	15880.5	102824	109119	32	392	7288	3.375×10^{-3}	5.645	−0.9665	AA	1
4−15	15700.7	102824	109191	32	450	5110	2.656×10^{-3}	4.392	−1.0706	AA	1
4−16	15556.5	102824	109250	32	512	3671	2.131×10^{-3}	3.492	−1.1662	AA	1
4−17	15438.9	102824	109299	32	578	2693	1.739×10^{-3}	2.827	−1.2547	AA	1
4−18	15341.8	102824	109340	32	648	2013	1.439×10^{-3}	2.324	−1.3370	AA	1
4−19	15260.6	102824	109375	32	722	1529	1.204×10^{-3}	1.936	−1.4141	AA	1
4−20	15191.8	102824	109405	32	800	1178	1.019×10^{-3}	1.631	−1.4865	AA	1

H—Table A. $(n)_i-(n)_k$ Transitions (Average Values)—*Continued*

Transition	λ(Å)	E_i(cm^{-1})	E_k(cm^{-1})	g_i	g_k	A_{ki}(sec^{-1})	f_{ik}	S(at.u.)	log gf	Accuracy	Source
5—6	74578	105292	106632	50	72	1.025×10^{6}	1.231	1.511×10^{4}	1.7893	AA	1
5—7	46525	105292	107440	50	98	3.253×10^{5}	0.2069	1584	1.0147	AA	1
5—8	37395	105292	107965	50	128	1.388×10^{5}	7.448×10^{-2}	458.3	0.5710	AA	1
5—9	32961	105292	108325	50	162	6.908×10^{4}	3.645×10^{-2}	197.7	0.2607	AA	1
5—10	30384	105292	108582	50	200	3.800×10^{4}	2.104×10^{-2}	105.2	0.0219	AA	1
5—11	28722	105292	108772	50	242	2.246×10^{4}	1.344×10^{-2}	63.55	−0.1725	AA	1
5—12	27575	105292	108917	50	288	1.402×10^{4}	9.209×10^{-3}	41.79	−0.3368	AA	1
5—13	26744	105292	109030	50	338	9148	6.631×10^{-3}	29.18	−0.4794	AA	1
5—14	26119	105292	109119	50	392	6185	4.959×10^{-3}	21.32	−0.6056	AA	1
5—15	25636	105292	109191	50	450	4308	3.821×10^{-3}	16.12	−0.7189	AA	1
5—16	25254	105292	109250	50	512	3079	3.014×10^{-3}	12.53	−0.8218	AA	1
5—17	24946	105292	109299	50	578	2249	2.425×10^{-3}	9.957	−0.9162	AA	1
5—18	24693	105292	109340	50	648	1675	1.984×10^{-3}	8.062	−1.0035	AA	1
5—19	24483	105292	109375	50	722	1268	1.646×10^{-3}	6.631	−1.0846	AA	1
5—20	24307	105292	109405	50	800	975.1	1.382×10^{-3}	5.528	−1.1605	AA	1
6—7	123680	106632	107440	72	98	4.561×10^{5}	1.424	4.173×10^{4}	2.0108	AA	1
6—8	75005	106632	107965	72	128	1.561×10^{5}	0.2340	4160	1.2266	AA	1
6—9	59066	106632	108325	72	162	7.065×10^{4}	8.315×10^{-2}	1164	0.7772	AA	1
6—10	51273	106632	108582	72	200	3.688×10^{4}	4.038×10^{-2}	490.6	0.4635	AA	1
6—11	46712	106632	108772	72	242	2.110×10^{4}	2.320×10^{-2}	256.8	0.2227	AA	1
6—12	43753	106632	108917	72	288	1.288×10^{4}	1.479×10^{-2}	153.3	0.0273	AA	1
6—13	41697	106632	109030	72	338	8271	1.012×10^{-2}	100.0	−0.1374	AA	1
6—14	40198	106632	109119	72	392	5526	7.289×10^{-3}	69.43	−0.2800	AA	1
6—15	39065	106632	109191	72	450	3815	5.455×10^{-3}	50.50	−0.4059	AA	1
6—16	38184	106632	109250	72	512	2707	4.207×10^{-3}	38.07	−0.5186	AA	1
6—17	37484	106632	109299	72	578	1966	3.324×10^{-3}	29.53	−0.6209	AA	1
6—18	36916	106632	109340	72	648	1457	2.679×10^{-3}	23.44	−0.7146	AA	1
6—19	36449	106632	109375	72	722	1099	2.196×10^{-3}	18.96	−0.8011	AA	1
6—20	36060	106632	109405	72	800	842.4	1.825×10^{-3}	15.59	−0.8815	AA	1
7—8	190570	107440	107965	98	128	2.272×10^{5}	1.616	9.931×10^{4}	2.1996	AA	1
7—9	113060	107440	108325	98	162	8.237×10^{4}	0.2609	9514	1.4077	AA	1
7—10	87577	107440	108582	98	200	3.905×10^{4}	9.163×10^{-2}	2588	0.9533	AA	1
7—11	75061	107440	108772	98	242	2.117×10^{4}	4.416×10^{-2}	1069	0.6363	AA	1
7—12	67701	107440	108917	98	288	1.250×10^{4}	2.525×10^{-2}	551.3	0.3935	AA	1
7—13	62902	107440	109030	98	338	7845	1.605×10^{-2}	325.7	0.1967	AA	1
7—14	59552	107440	109119	98	392	5156	1.097×10^{-2}	210.6	0.0313	AA	1
7—15	57099	107440	109191	98	450	3516	7.891×10^{-3}	145.3	−0.1116	AA	1
7—16	55237	107440	109250	98	512	2471	5.905×10^{-3}	105.2	−0.2376	AA	1
7—17	53783	107440	109299	98	578	1781	4.556×10^{-3}	79.03	−0.3502	AA	1
7—18	52622.5	107440	109340	98	648	1312	3.602×10^{-3}	61.13	−0.4522	AA	1
7—19	51679	107440	109375	98	722	984.9	2.905×10^{-3}	48.43	−0.5456	AA	1
7—20	50899	107440	109405	98	800	751.7	2.383×10^{-3}	39.13	−0.6316	AA	1
8—9	277960	107965	108325	128	162	1.233×10^{5}	1.807	2.116×10^{5}	2.3642	AA	1
8—10	162050	107965	108582	128	200	4.676×10^{4}	0.2876	1.964×10^{4}	1.5661	AA	1
8—11	123840	107965	108772	128	242	2.301×10^{4}	0.1000	5217	1.1072	AA	1
8—12	105010	107965	108917	128	288	1.287×10^{4}	4.787×10^{-2}	2117	0.7873	AA	1
8—13	93894	107965	109030	128	338	7804	2.724×10^{-2}	1077	0.5424	AA	1
8—14	86621	107965	109119	128	392	5010	1.726×10^{-2}	629.8	0.3442	AA	1
8—15	81527	107965	109191	128	450	3359	1.177×10^{-2}	404.1	0.1778	AA	1
8—16	77782	107965	109250	128	512	2331	8.456×10^{-3}	277.1	0.0344	AA	1
8—17	74930	107965	109299	128	578	1664	6.323×10^{-3}	199.6	−0.0919	AA	1
8—18	72696	107965	109340	128	648	1216	4.877×10^{-3}	149.4	−0.2046	AA	1
8—19	70908	107965	109375	128	722	906.9	3.856×10^{-3}	115.2	−0.3066	AA	1
8—20	69448	107965	109405	128	800	688.6	3.112×10^{-3}	91.04	−0.3998	AA	1

H—Table A. $(n)_i-(n)_k$ Transitions (Average Values)—*Continued*

Transition	λ(Å)	E_i(cm^{-1})	E_k(cm^{-1})	g_i	g_k	A_{ki}(sec^{-1})	f_{ik}	S(at.u.)	log gf	Accuracy	Source
9—10	388590	108325	108582	162	200	7.151×10^{4}	1.999	4.141×10^{5}	2.5103	AA	1
9—11	223340	108325	108772	162	242	2.813×10^{4}	0.3143	3.742×10^{4}	1.7068	AA	1
9—12	168760	108325	108917	162	288	1.427×10^{4}	0.1083	9746	1.2442	AA	1
9—13	141790	108325	109030	162	338	8192	5.152×10^{-2}	3895	0.9215	AA	1
9—14	125840	108325	109119	162	392	5080	2.918×10^{-2}	1958	0.6746	AA	1
9—15	115360	108325	109191	162	450	3325	1.843×10^{-2}	1134	0.4750	AA	1
9—16	108010	108325	109250	162	512	2268	1.254×10^{-2}	721.9	0.3077	AA	1
9—17	102580	108325	109299	162	578	1598	8.995×10^{-3}	492.0	0.1635	AA	1
9—18	98443	108325	109340	162	648	1156	6.719×10^{-3}	352.7	0.0368	AA	1
9—19	95191	108325	109375	162	722	855.5	5.180×10^{-3}	262.9	−0.0762	AA	1
9—20	92579	108325	109405	162	800	645.2	4.094×10^{-3}	202.1	−0.1783	AA	1
10—11	525200	108582	108772	200	242	4.377×10^{4}	2.190	7.571×10^{5}	2.6415	AA	1
10—12	298310	108582	108917	200	288	1.774×10^{4}	0.3408	6.692×10^{4}	1.8335	AA	1
10—13	223250	108852	109030	200	338	9231	0.1166	1.713×10^{4}	1.3676	AA	1
10—14	186100	108582	109119	200	392	5417	5.513×10^{-2}	6753	1.0424	AA	1
10—15	164070	108582	109191	200	450	3424	3.109×10^{-2}	3358	0.7937	AA	1
10—16	149580	108582	109250	200	512	2280	1.958×10^{-2}	1927	0.5928	AA	1
10—17	139380	108582	109299	200	578	1578	1.328×10^{-2}	1219	0.4243	AA	1
10—18	131840	108582	109340	200	648	1127	9.515×10^{-3}	825.8	0.2794	AA	1
10—19	126080	108582	109375	200	722	825.2	7.099×10^{-3}	589.2	0.1522	AA	1
10—20	121530	108582	109405	200	800	617.3	5.468×10^{-3}	437.4	0.0389	AA	1
11—12	690500	108772	108917	242	288	2.799×10^{4}	2.381	1.310×10^{6}	2.7606	AA	1
11—13	388320	108772	109030	242	338	1.163×10^{4}	0.3673	1.136×10^{5}	1.9489	AA	1
11—14	288230	108772	109119	242	392	6186	0.1248	2.865×10^{4}	1.4800	AA	1
11—15	238620	108772	109191	242	450	3699	5.872×10^{-2}	1.116×10^{4}	1.1526	AA	1
11—16	209150	108772	109250	242	512	2377	3.298×10^{-2}	5495	0.9021	AA	1
11—17	189730	108772	109299	242	578	1606	2.070×10^{-2}	3129	0.6999	AA	1
11—18	176030	108772	109340	242	648	1127	1.402×10^{-2}	1965	0.5304	AA	1
11—19	165900	108772	109375	242	722	814.1	1.002×10^{-2}	1324	0.3848	AA	1
11—20	158120	108772	109405	242	800	602.6	7.468×10^{-3}	940.5	0.2570	AA	1
12—13	887300	108917	109030	288	338	1.857×10^{4}	2.572	2.163×10^{6}	2.8697	AA	1
12—14	494740	108917	109119	288	392	7884	0.3938	1.847×10^{5}	2.0547	AA	1
12—15	364610	108917	109191	288	450	4271	0.1330	4.596×10^{4}	1.5832	AA	1
12—16	300020	108917	109250	288	512	2596	6.228×10^{-2}	1.771×10^{4}	1.2538	AA	1
12—17	261610	108917	109299	288	578	1693	3.486×10^{-2}	8644	1.0017	AA	1
12—18	236260	108917	109340	288	648	1159	2.182×10^{-2}	4886	0.7982	AA	1
12—19	218360	108917	109375	288	722	822.3	1.474×10^{-2}	3050	0.6278	AA	1
12—20	205090	108917	109405	288	800	600.5	1.052×10^{-2}	2045	0.4814	AA	1
13—14	1118000	109030	109119	338	392	1.271×10^{4}	2.763	3.438×10^{6}	2.9703	AA	1
13—15	619000	109030	109191	338	450	5496	0.4202	2.894×10^{5}	2.1524	AA	1
13—16	453290	109030	109250	338	512	3026	0.1412	7.119×10^{4}	1.6787	AA	1
13—17	371000	109030	109299	338	578	1866	6.584×10^{-2}	2.717×10^{4}	1.3474	AA	1
13—18	322000	109030	109340	338	648	1232	3.672×10^{-2}	1.316×10^{4}	1.0939	AA	1
13—19	289640	109030	109375	338	722	853.2	2.292×10^{-2}	7386	0.8892	AA	1
13—20	266740	109030	109405	338	800	611.9	1.545×10^{-2}	4584	0.7178	AA	1
14—15	1386000	109119	109191	392	450	8933	2.954	5.284×10^{6}	3.0637	AA	1
14—16	762300	109119	109250	392	512	3926	0.4467	4.393×10^{5}	2.2433	AA	1
14—17	555200	109119	109299	392	578	2192	0.1494	1.070×10^{5}	1.7675	AA	1
14—18	452220	109119	109340	392	648	1369	6.938×10^{-2}	4.048×10^{4}	1.4345	AA	1

H—Table A. $(n)_i-(n)_k$ Transitions (Average Values)—*Continued*

Transition	λ(Å)	E_i(cm^{-1})	E_k(cm^{-1})	g_i	g_k	A_{ki}(sec^{-1})	f_{ik}	S(at.u.)	log gf	Accuracy	Source
14—19	390880	109119	109375	392	722	914.4	3.858×10^{-2}	1.946×10^{4}	1.1796	AA	1
14—20	350300	109119	109405	392	800	639.7	2.402×10^{-2}	1.086×10^{4}	0.9738	AA	1
15—16	1694000	109191	109250	450	512	6429	3.145	7.889×10^{6}	3.1509	AA	1
15—17	926100	109191	109299	450	578	2864	0.4731	6.489×10^{5}	2.3281	AA	1
15—18	671200	109191	109340	450	648	1620	0.1575	1.566×10^{5}	1.8505	AA	1
15—19	544400	109191	109375	450	722	1023	7.292×10^{-2}	5.879×10^{4}	1.5160	AA	1
15—20	468760	109191	109405	450	800	690.3	4.043×10^{-2}	2.807×10^{4}	1.2599	AA	1
16—17	2044000	109250	109299	512	578	4720	3.336	1.149×10^{7}	3.2325	AA	1
16—18	1112000	109250	109340	512	648	2130	0.4995	9.358×10^{5}	2.4078	AA	1
16—19	802300	109250	109375	512	722	1217	0.1657	2.240×10^{5}	1.9285	AA	1
16—20	648200	109250	109405	512	800	776.7	7.644×10^{-2}	8.349×10^{4}	1.5926	AA	1
17—18	2438000	109299	109340	578	648	3530	3.527	1.636×10^{7}	3.3094	AA	1
17—19	1321000	109299	109375	578	722	1610	0.5259	1.321×10^{6}	2.4828	AA	1
17—20	949200	109299	109405	578	800	929.6	0.1738	3.139×10^{5}	2.0020	AA	1
18—19	2882000	109340	109375	648	722	2680	3.718	2.285×10^{7}	3.3819	AA	1
18—20	1554000	109340	109405	648	800	1235	0.5523	1.831×10^{6}	2.5537	AA	1
19—20	3374000	109375	109405	722	800	2067	3.909	3.134×10^{7}	3.4506	AA	1

H—Table B. $(nl)_i-(nl)_k$ Transitions

Transition	λ(Å)	E_i(cm^{-1})	E_k(cm^{-1})	g_i	g_k	A_{ki}(sec^{-1})	f_{ik}	S(at.u.)	log gf	Accuracy	Source
$1s-2p$	1215.67	0	82259	2	6	6.265×10^{8}	0.4162	3.330	−0.0797	AA	1
$1s-3p$	1025.72	0	97492	2	6	1.672×10^{8}	7.910×10^{-2}	0.5339	−0.8008	AA	1
$1s-4p$	972.537	0	102824	2	6	6.818×10^{7}	2.899×10^{-2}	0.1855	−1.2367	AA	1
$1s-5p$	949.743	0	105292	2	6	3.437×10^{7}	1.394×10^{-2}	8.711×10^{-2}	−1.5548	AA	1
$1s-6p$	937.804	0	106632	2	6	1.973×10^{7}	7.800×10^{-3}	4.813×10^{-2}	−1.8069	AA	1
$2p-3s$	6562.86	82259	97492	6	2	6.313×10^{6}	1.359×10^{-2}	1.761	−1.0886	AA	1
$2p-4s$	4861.35	82259	102824	6	2	2.578×10^{6}	3.045×10^{-3}	0.2923	−1.7383	AA	1
$2p-5s$	4340.48	82259	105292	6	2	1.289×10^{6}	1.213×10^{-3}	0.1040	−2.1379	AA	1
$2p-6s$	4101.75	82259	106632	6	2	7.350×10^{5}	6.180×10^{-4}	5.006×10^{-2}	−2.4309	AA	1
$2s-3p$	6562.74	82259	97492	2	6	2.245×10^{7}	0.4349	18.79	−0.0606	AA	1
$2s-4p$	4861.29	82259	102824	2	6	9.668×10^{6}	0.1028	3.288	−0.6871	AA	1
$2s-5p$	4340.44	82259	105292	2	6	4.948×10^{6}	4.193×10^{-2}	1.198	−1.0764	AA	1
$2s-6p$	4101.71	82259	106632	2	6	2.858×10^{6}	2.163×10^{-2}	0.5840	−1.3639	AA	1
$2p-3d$	6562.81	82259	97492	6	10	6.465×10^{7}	0.6958	90.17	0.6206	AA	1
$2p-4d$	4861.33	82259	102824	6	10	2.062×10^{7}	0.1218	11.69	−0.1362	AA	1
$2p-5d$	4340.47	82259	105292	6	10	9.425×10^{6}	4.437×10^{-2}	3.803	−0.5748	AA	1
$2p-6d$	4101.74	82259	106632	6	10	5.145×10^{6}	2.163×10^{-2}	1.752	−0.8868	AA	1

H – Table B. $(nl)_i - (nl)_k$ Transitions. – *Continued*

Transition	λ(Å)	E_i(cm^{-1})	E_k(cm^{-1})	g_i	g_k	A_{ki}(sec^{-1})	f_{ik}	S(at.u.)	log gf	Accuracy	Source
$3s-4p$	18750.8	97492	102824	2	6	3.065×10^{6}	0.4847	59.83	−0.0135	AA	1
$3s-5p$	12818.0	97492	105292	2	6	1.638×10^{6}	0.1210	10.21	−0.6161	AA	1
$3s-6p$	10938.0	97492	106632	2	6	9.551×10^{5}	5.139×10^{-2}	3.700	−0.9881	AA	1
$3p-4s$	18751.1	97492	102824	6	2	1.835×10^{6}	3.225×10^{-2}	11.94	−0.7133	AA	1
$3p-5s$	12818.1	97492	105292	6	2	9.046×10^{5}	7.428×10^{-3}	1.880	−1.3510	AA	1
$3p-6s$	10938.1	97492	106632	6	2	5.071×10^{5}	3.032×10^{-3}	0.6550	−1.7401	AA	1
$3p-4d$	18750.9	97492	102824	6	10	7.037×10^{6}	0.6183	228.9	0.5693	AA	1
$3p-5d$	12818.0	97492	105292	6	10	3.391×10^{6}	0.1392	35.24	−0.0781	AA	1
$3p-6d$	10938.1	97492	106632	6	10	1.878×10^{6}	5.614×10^{-2}	12.13	−0.4726	AA	1
$3d-4p$	18751.2	97492	102824	10	6	3.475×10^{5}	1.099×10^{-2}	6.783	−0.9589	AA	1
$3d-5p$	12818.2	97492	105292	10	6	1.495×10^{5}	2.210×10^{-3}	0.9324	−1.6556	AA	1
$3d-6p$	10938.1	97492	106632	10	6	7.824×10^{4}	8.420×10^{-4}	0.3031	−2.0747	AA	1
$3d-4f$	18751.1	97492	102824	10	14	1.379×10^{7}	1.018	628.0	1.0075	AA	1
$3d-5f$	12818.1	97492	105292	10	14	4.542×10^{6}	0.1566	66.08	0.1949	AA	1
$3d-6f$	10938.1	97492	106632	10	14	2.146×10^{6}	5.389×10^{-2}	19.40	−0.2685	AA	1
$4s-5p$	40511	102824	105292	2	6	7.372×10^{5}	0.5442	145.1	0.0368	AA	1
$4s-6p$	26251	102824	106632	2	6	4.456×10^{5}	0.1381	23.87	−0.5587	AA	1
$4p-5s$	40512	102824	105292	6	2	6.450×10^{5}	5.291×10^{-2}	42.33	−0.4983	AA	1
$4p-6s$	26251	102824	106632	6	2	3.582×10^{5}	1.234×10^{-2}	6.396	−1.1306	AA	1
$4p-5d$	40511	102824	105292	6	10	1.486×10^{6}	0.6093	487.4	0.5630	AA	1
$4p-6d$	26251	102824	106632	6	10	8.622×10^{5}	0.1485	76.96	−0.0502	AA	1
$4d-5p$	40512	102824	105292	10	6	1.884×10^{5}	2.782×10^{-2}	37.10	−0.5556	AA	1
$4d-6p$	26252	102824	106632	10	6	9.416×10^{4}	5.837×10^{-3}	5.044	−1.2338	AA	1
$4d-5f$	40512	102824	105292	10	14	2.584×10^{6}	0.8903	1187	0.9495	AA	1
$4d-6f$	26252	102824	106632	10	14	1.287×10^{6}	0.1862	160.8	0.2699	AA	1
$4f-5d$	40512	102824	105292	14	10	5.047×10^{4}	8.871×10^{-3}	16.56	−0.9059	AA	1
$4f-6d$	26252	102824	106632	14	10	2.145×10^{4}	1.583×10^{-3}	1.915	−1.6544	AA	1
$4f-5g$	40512	102824	105292	14	18	4.254×10^{6}	1.346	2512	1.2751	AA	1
$4f-6g$	26252	102824	106632	14	18	1.373×10^{6}	0.1824	220.6	0.4070	AA	1
$5s-6p$	74577	105292	106632	2	6	2.430×10^{5}	0.6078	298.4	0.0848	AA	1
$5p-6s$	74578	105292	106632	6	2	2.682×10^{5}	7.454×10^{-2}	109.8	−0.3495	AA	1
$5p-6d$	74578	105292	106632	6	10	4.495×10^{5}	0.6247	920.0	0.5738	AA	1
$5d-6p$	74579	105292	106632	10	6	9.593×10^{4}	4.800×10^{-2}	117.8	−0.3188	AA	1
$5d-6f$	74578	105292	106632	10	14	7.232×10^{5}	0.8443	2072	0.9265	AA	1
$5f-6d$	74579	105292	106632	14	10	3.908×10^{4}	2.328×10^{-2}	79.98	−0.4870	AA	1
$5f-6g$	74578	105292	106632	14	18	1.106×10^{6}	1.185	4073	1.2200	AA	1
$5g-6f$	74579	105292	106632	18	14	1.137×10^{4}	7.376×10^{-3}	32.59	−0.8769	AA	1
$5g-6h$	74578	105292	106632	18	22	1.645×10^{6}	1.676	7406	1.4796	AA	1