The Arc Spectrum of Selenium[1, 2]

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The arc spectrum of selenium, as excited by means of a positive column discharge in helium, has been photographed over the wave-length range 300–11,000A. Four different grating spectrographs were used having dispersions of from 11 to 2.5A per mm. A total of 510 lines has been measured as belonging to the arc spectrum and of these 391 have been classified. Seven series built on the ^4S state of the ion have been carried to five or more members and the absolute term values are determined to within 0.2 cm^{-1}. All the $4p^4$, $4p^3(^2D)\ 5s$, $4p^3(^2P)\ 5s$, and $4p^3(^2D)\ 5p$ terms have been located and also some of the $4p^3(^2D)\ 4d$ terms. Perturbation effects are frequently evident and are illustrated by plots of the various series.

A HOLLOW cathode discharge tube, described in a recent paper,[4] was first used for the production of the selenium spectrum, but difficulty in maintaining the glow within the cathode when selenium vapor was condensing upon it (as was also previously experienced when using sulfur) made a different method of excitation desirable. A positive column tube with water cooled electrodes functioned more satisfactorily in nearly all respects. The discharge occurring in a tube of $\frac{3}{4}$ inch diameter and 1 foot length was photographed endwise, circulated helium being used to maintain the discharge. The selenium was vaporized as desired from a small side tube. By increasing the density of selenium vapor, spark lines were decreased in intensity while arc lines were increased, and if carried sufficiently far, strong bands were produced from 2600–6000A, with arc lines very prominent and spark lines almost absent. With the one known exception of mercury, all impurity lines were also decreased in intensity by this same procedure. In each spectral region two exposures were made on the same plate, one with a low and the other with a high density of selenium vapor. The tube was generally run at 0.8 ampere d.c. supplied by an a.c. rectifier set.

The region from 300–2550A was photographed with a 1.5 meter grating in a vacuum spectrograph giving a dispension of 11A per mm, from 2550–6550A with a 21-foot grating in a Wadsworth mounting giving a dispersion of 2.5 per mm, and from 6550–10,400A with a 7-foot grating in a Rowland mounting giving a dispersion of 8.3A per mm. Two lines were also observed at still longer wave-lengths using a Zeiss triple prism spectrograph which gave a dispersion of about 125A per mm in that region. Schumann plates were used for the vacuum wave-lengths and Eastman plates of suitable sensitizations over the rest of the range. The vacuum wave-lengths have a maximum error of 0.07A, which corresponds to about 3 cm^{-1}. The stronger lines from 1890–2420A were measured in the second order of the 21 foot grating and their accuracy is believed to be within 0.01A, which gives a wave number accuracy of about 0.2 cm^{-1} for some transitions involving the deepest terms. The wave-length accuracy from 2550 to 10,400A varies, but the wave number errors are always within 0.2 cm^{-1}.

Previous work has been done by several investigators[5, 6, 7, 8, 9] leading to a partial analysis of the selenium arc spectrum. The data, however, were quite incomplete and as shown by the present work some of the term assignments were incorrect. The more complete data yield 103 classified lines for the vacuum region and 288 for the longer wave-lengths. From these a total of 130 terms are established, of which 100 are new. All the stronger lines have been classified,

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[2] A report on the subject matter in this paper was read at a meeting of the American Physical Society, April, 1934. Phys. Rev. **45**, 747 (1934).

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TABLE I. *Lines of Se I.*

Int.	λ(air)	ν(vac)	Transition
2	10652.7	9387.3	$(^2D)5s\,^1D_2-(^2D)5p\,^1P_1$
1	10533.4	9493.6	$(^4S)4d\,^5D_2-(^2D)5p\,^1P_1$
10	10386.28	9625.45	$(^4S)5s\,^3S_1-(^4S)5p\,^3P_1$
12	10327.19	9680.52	$(^4S)5s\,^3S_1-(^4S)5p\,^3P_2$
8	10307.39	9699.11	$(^4S)5s\,^3S_1-(^4S)5p\,^3P_0$
6	10217.26	9784.68	$(^2D)5s\,^1D_2-(^2D)5p\,^1F_3$
1	10132.40	9866.62	$(^4S)4d\,^5D_3-(^2D)5p\,^3F_4$
2	10107.52	9890.91	$(^4S)4d\,^5D_2-(^2D)5p\,^1F_3$
1	10086.45	9911.58	
4	9969.73	10027.62	$(^2D)5s\,^3D_2-(^2D)5p\,^3D_1$
1	9938.09	10059.54	
6	9825.51	10174.80	$(^2D)5s\,^3D_1-(^2D)5p\,^3D_1$
2	9816.63	10184.00	
1	9754.19	10249.20	$(^4S)4d\,^3D_3-(^4S)7f\,^3F$
1	9716.00	10289.48	$(^4S)4d\,^3D_1-(^4S)7f\,^3F$
1	9695.76	10310.96	$(^4S)4d\,^3D_2-(\;S)7f\,^3F$
1	9603.34	10410.19	$(^4S)5p\,^3P_0-(^4S)5d\,^3D_1$
2	9595.41	10418.79	$(^4S)5p\,^3P_2-(^4S)5d\,^3D_2$
7	9549.40	10468.99	$(^2D)5s\,^3D_3-(^2D)5p\,^3F_3$
3	9544.96	10473.86	$(^4S)5p\,^3P_1-(^4S)5d\,^3D_2$
5	9541.64	10477.50	$(^4S)5p\,^3P_2-(^4S)5d\,^3D_3$
1	9535.83	10483.88	$(^4S)5p\,^3P_1-(^4S)5d\,^3D_1$
1	9517.91	10503.63	
10	9432.43	10598.81	$(^2D)5s\,^3D_2-(^2D)5p\,^3D_2$
0	9427.43	10604.44	$(^2D)5s\,^1D_2-(^2D)5p\,^3P_1$
0	9419.85	10612.97	$(^2D)5s\,^1D_2-(^2D)5p\,^3P_2$
1	9329.83	10715.37	
1	9329.15	10716.15	
2	9303.15	10746.10	$(^2D)5s\,^3D_1-(^2D)5p\,^3D_2$
6	9271.02	10783.35	$(^2D)5s\,^3D_3-(^2D)5p\,^3D_3$
1	9265.41	10789.87	$(^2D)5s\,^3D_2-(^2D)5p\,^3F_2$
2	9252.40	10805.04	$(^2D)5s\,^3D_3-(^4S)7p\,^3P_2$
1	9228.03	10833.58	
2	9218.30	10845.01	$(^4S)4d\,^5D_3-(^4S)6f\,^5F$
0	9216.81	10846.76	$(^2D)5s\,^3D_3-(^4S)7p\,^5P_2$
1	9214.28	10849.74	$(^4S)4d\,^5D_1-(^4S)6f\,^5F$
1	9212.77	10851.52	$(^4S)4d\,^5D_0-(^4S)6f\,^5F$
1	9211.04	10853.56	$(^2D)5s\,^3D_3-(^4S)7p\,^5P_3$
2	9206.14	10859.33	$(^4S)4d\,^5D_2-(^4S)6f\,^5F$
3	9203.58	10862.36	$(^4S)4d\,^5D_4-(^4S)6f\,^5F$
6	9181.80	10888.12	$(^2D)5s\,^3D_2-(^2D)5p\,^3F_3$
8	9140.79	10936.98	$(^2D)5s\,^3D_1-(^2D)5p\,^3F_2$
0	9090.26	10997.77	$(^4S)5p\,^5P_3-(^4S)5d\,^5D_2$
12	9088.70	10999.66	$(^4S)5p\,^5P_3-(^4S)5d\,^5D_4$
6	9088.14	11000.34	$(^4S)5p\,^5P_3-(^4S)5d\,^5D_3$
8	9083.05	11006.50	$(^2D)5s\,^3D_3-(^2D)5p\,^3F_4$
0	9074.86	11016.43	$(^2D)5s\,^3D_3-(^2D)5p\,^1F_3$
20	9038.56	11060.67	$(^4S)5s\,^5S_2-(^4S)5p\,^5P_1$
0	9035.05	11064.97	$(^4S)4d\,^3D_3-(^4S)8f\,^3F$
3	9005.99	11100.66	$(^4S)5p\,^5P_2-(^4S)5d\,^5D_1$
7	9005.58	11101.17	$(^4S)5p\,^5P_2-(^4S)5d\,^5D_2$
8	9003.44	11103.82	$(^4S)5p\,^5P_2-(^4S)5d\,^5D_3$
20	9001.93	11105.68	$(^4S)5s\,^5S_2-(^4S)5p\,^5P_2$
10	8969.63	11145.68	$(^4S)5p\,^5P_1-(^4S)5d\,^5D_1$
8	8969.23	11146.17	$(^4S)5p\,^5P_1-(^4S)5d\,^5D_2$
9	8938.14	11184.94	$(^2D)5s\,^3D_1-(^2D)5p\,^1P_1$
1	8930.67	11194.30	$(^4S)5p\,^3P_0-(^4S)7s\,^3S_1$
3	8924.19	11202.42	$(^2D)5s\,^3D_2-(^2D)5p\,^3D_3$
30	8918.80	11209.19	$(^4S)5s\,^5S_2-(^4S)5p\,^5P_3$
4	8915.88	11212.86	$(^4S)5p\,^3P_2-(^4S)7s\,^3S_1$
4	8914.58	11214.50	$(^2D)5s\,^3D_2-(^4S)7p\,^3P_1$
1	8882.72	11254.72	$(^2D)5s\,^3D_2-(^4S)7p\,^5P_1$
3	8872.26	11268.11	$(^4S)5p\,^3P_1-(^4S)7s\,^3S_1$
0	8868.51	11272.75	$(^2D)5s\,^3D_2-(^4S)7p\,^5P_3$
3	8799.79	11360.78	$(^2D)5s\,^3D_1-(^4S)7p\,^3P_0$
1	8791.73	11372.49	
15	8742.29	11435.51	$(^2D)5s\,^3D_2-(^2D)5p\,^1F_3$
0	8666.30	11535.78	
0	8663.11	11540.03	
0	8654.77	11515.15	
1	8651.54	11555.47	
2	8568.39	11670.33	
1	8495.97	11767.06	
1	8491.35	11773.46	
15	8450.47	11830.41	$(^2D)5s\,^1D_2-(^2D)5p\,^1D_2$
15	8440.55	11844.31	$(^2D)5s\,^3D_3-(^2D)5p\,^3P_2$
1	8425.16	11865.96	
1	8423.76	11867.93	
8	8375.31	11936.58	$(^4S)4d\,^5D_2-(^2D)5p\,^1D_2$
1	8368.57	11946.19	$(^4S)5p\,^3P_1-(^2P)5s\,^1P_1$
1	8368.25	11946.65	
0	8367.44	11947.80	
0	8356.26	11963.78	
2	8350.60	11971.89	
1d	8341.64	11984.75	$(^2D)5s\,^3D_3-(^4S)6f\,^5F$
4	8340.03	11987.06	$(^2D)5s\,^3D_3-(^4S)6f\,^3F$
0	8335.14	11994.10	
1	8309.52	12031.09	
0	8304.66	12038.13	
1	8282.40	12070.47	
1	8274.55	12081.92	
2	8272.45	12085.00	
0	8265.34	12095.39	
1	8258.24	12105.79	
2	8256.74	12107.99	$(^2D)5s\,^1D_2-(^4S)7f\,^5F$
0d	8255.78	12109.40	
0	8253.04	12113.42	
1	8217.53	12165.76	
12	8194.61	12199.79	$(^4S)4d\,^5D_3-(^4S)7f\,^5F$
8	8191.43	12204.53	$(^4S)4d\,^5D_1-(^4S)7f\,^5F$
4	8190.13	12206.47	$(^4S)4d\,^5D_0-(^4S)7f\,^5F$
10	8185.00	12214.11	$(^4S)4d\,^5D_2-(^4S)7f\,^5F$
15	8182.93	12217.20	$(^4S)4d\,^5D_4-(^4S)7f\,^5F$
0	8172.00	12233.54	
18	8163.08	12246.92	$(^4S)5p\,^5P_3-(^4S)7s\,^5S_2,\ (^2P)5z\,^3P_2$
20	8157.73	12254.95	$(^2D)5s\,^3D_2-(^2D)5p\,^3P_1$
3	8155.69	12258.01	
15	8152.02	12263.53	$(^2D)5s\,^3D_2-(^2D)5p\,^3P_2$
18	8149.28	12267.65	$(^4S)5p\,^5P_3-(^2P)5s\,^3P_2,\ (^4S)7s\ 5S_2$
1	8147.09	12270.95	
0	8140.17	12281.38	
2	8098.51	12344.57	
15	8094.69	12350.39	$(^4S)5p\,^5P_2-(^4S)7s\,^5S_2,\ (^2P)5s\,^3P_2$
15	8093.19	12352.68	$(^2D)5s\,^3D_1-(^2D)5p\,^3P_0$
2	8087.77	12360.95	
12	8081.14	12371.09	$(^4S)5p\,^5P_2-(^2P)5s\,^3P_2,\ (^4S)7s\,^5S_2$
12	8065.31	12395.37	$(^4S)5p\,^5P_1-(^4S)7s\,^5S_2,\ (^2P)5s\,^3P_2$
12	8060.91	12402.15	$(^2D)5s\,^3D_1-(^2D)5p\,^3P_1$
1	8058.60	12405.70	
4	8058.37	12406.06	$(^2D)5s\,^3D_2-(^4S)6f\,^3F$
1	8055.29	12410.80	$(^2D)5s\,^3D_1-(^2D)5p\,^3P_2$
10	8051.81	12416.16	$(^4S)5p\,^5P_1-(^2P)5s\,^3P_2,\ (^4S)7s\,^5S_2$
1d	8043.62	12428.80	
20	8036.35	12440.04	$(^4S)5s\,^5S_2-(^4S)5p\,^3P_1$
1	8029.14	12451.21	
1	8024.18	12458.90	
1	8020.62	12464.45	
1	8018.42	12467.86	
30	8000.96	12495.06	$(^4S)5s\,^5S_2-(^4S)5p\,^3P_2$
0	7979.51	12528.66	
3	7963.89	12553.23	$(^2D)5s\,^3D_1-(^4S)6f\,^3F$
0	7960.67	12558.30	
0d	7958.20	12562.20	
0	7934.70	12599.41	
1	7932.83	12602.38	$(^4S)5p\,^5P_2-(^4S)7s\,^3S_1$
3	7929.48	12607.70	
0d	7924.16	12616.16	
0d	7916.20	12628.85	
0	7904.59	12647.39	$(^4S)5p\,^5P_1-(^4S)7s\,^3S_1$
0d	7902.07	12651.42	
1	7796.15	12823.32	
1	7771.60	12863.82	$(^4S)5p\,^3P_2-(^4S)6d\,^5D_2$
0	7770.26	12866.04	$(^4S)5p\,^3P_2-(^4S)6\mathrm{d}\,^5D_1$
2	7767.87	12870.00	{ $(^4S)5p\,^3P_2-(^4S)6d\,^5D_3$ { $4p^4\,^1D_2-4p^4\,^1S_0$
0	7766.88	12871.64	
0	7756.53	12888.81	
1	7754.51	12892.16	
5	7750.41	12899.00	$(^2D)5s\,^3D_3-(^4S)8p\,^3P_2$
0	7737.00	12921.35	$(^4S)5p\,^3P_1-(^4S)6d\,^5D_1$
0d	7735.16	12924.42	$(^2D)5s\,^1D_2-(^4S)8f\,^5F$
1	7724.04	12943.02	
6	7680.61	13016.22	$(^4S)4d\,^5D_3-(^4S)8f\,^5F$
3	7677.83	13020.94	$(^4S)4d\,^5D_1-(^4S)8f\,^5F$
1	7676.69	13022.87	$(^4S)4d\,^5D_0-(^4S)8f\,^5F$
1	7674.82	13026.04	
1	7672.39	13030.00	
4	7672.17	13030.54	$(^4S)4d\,^5D_2-(^4S)8f\,^5F$
8	7670.33	13033.66	$(^4S)4d\,^5D_4-(^4S)8f\,^5F$
8	7653.59	13062.18	$(^2D)5s\,^3D_3-(^2D)5p\,^1D_2$
12	7606.81	13142.50	$(^4S)5p\,^3P_2-(^4S)6d\,^3D_2$
15	7592.19	13167.81	$(^4S)5p\,^3P_0-(^4S)6d\,^3D_1$
0	7587.16	13176.53	
25	7583.37	13183.12	$(^4S)5p\,^3P_2-(^4S)6d\,^3D_3$
1	7581.47	13186.42	$(^4S)5p\,^3P_2-(^4S)6d\,^3D_1$
20	7575.08	13197.56	$(^4S)5p\,^3P_1-(^4S)6d\,^3D_2$
10	7549.97	13241.44	$(^4S)5p\,^3P_1-(^4S)6d\,^3D_1$
10	7508.97	13313.74	$(^2D)5s\,^3D_2-(^4S)8p\,^3P_1$
5	7506.44	13318.22	$(^2D)5s\,^3D_2-(^4S)8p\,^3P_2$
0	7494.39	13339.65	$(^2D)5s\,^3D_3-(^4S)7f\,^5F$
3	7493.47	13341.28	$(^2D)5s\,^3D_3-(^4S)7f\,^3F$
0	7430.72	13453.95	$(^2D)5s\,^1D_2-(^4S)9f\,^5F$
8	7429.27	13456.58	$(^2D)5s\,^3D_1-(^4S)8p\,^3P_0$
7	7426.81	13461.03	$(^2D)5s\,^3D_1-(^4S)8p\,^3P_1$
0	7424.39	13465.42	$(^2D)5s\,^3D_1-(^4S)8p\,^3P_2$
1	7415.58	13481.41	$(^2D)5s\,^3D_2-(^2D)5p\,^1D_2$
2	7414.02	13484.25	$(^4S)5p\,^3P_2-(^2D)4d\ 1_2,\quad (^4S)8s\,^5S_2$
6	7383.88	13539.27	$(^4S)5p\,^3P_1-(^2D)4d\ 1_2,\quad (^4S)8s\,^5S_2$
5	7380.34	13545.79	$(^4S)4d\,^5D_3-(^4S)9f\,^5F$
3	7377.77	13550.50	$(^4S)4d\,^5D_1-(^4S)9f\,^5F$
1	7376.75	13552.38	$(^4S)4d\,^5D_0-(^4S)9f\,^5F$
4	7372.54	13560.11	$(^4S)4d\,^5D_2-(^4S)9f\,^5F$
6	7370.82	13563.28	$(^4S)4d\,^5D_4-(^4S)9f\,^5F$
0	7357.53	13587.79	$(^4S)5p\,^3P_1-(^4S)8s\,^5S_2,\ (^2D)4d\ 1_2$

TABLE I.—*Continued.*

Int.	λ(air)	ν(vac)	Transition
4	7338.96	13622.16	$(^4S)5p\,^3P_0-(^4S)8s\,^4S_1$
1	7335.51	13628.56	$(^2D)5s\,^3D_1-(^2D)5p\,^1D_2$
10	7328.97	13640.72	$(^4S)5p\,^3P_2-(^4S)8s\,^3S_1$
0	7319.18	13658.96	
8	7299.51	13695.78	$(^4S)5p\,^3P_1-(^4S)8s\,^3S_1$
0	7287.53	13718.29	
0	7266.13	13758.70	$(^2D)5s\,^3D_2-(^4S)7f\,^5F$
3	7265.31	13760.25	$(^2D)5s\,^3D_2-(^4S)7f\,^3F$
0d	7256.48	13776.99	
4	7210.04	13865.72	$(^2D)5s\,^3D_3-(^4S)9p\,^3P_2$
2	7188.31	13907.64	$(^2D)5s\,^3D_1-(^4S)7f\,^3F$
2	7187.86	13908.52	$(^4S)4d\,^5D_3-(^4S)10f\,^5F$
1	7185.46	13913.16	$(^4S)4d\,^5D_1-(^4S)10f\,^5F$
1	7180.49	13922.79	$(^4S)4d\,^5D_2-(^4S)10f\,^5F$
3	7178.84	13925.99	$(^4S)4d\,^5D_4-(^4S)10f\,^5F$
1	7099.70	14081.21	
0	7069.59	14141.21	
1	7062.49	14155.42	
30	7062.06	14156.28	$(^4S)5p\,^5P_3-(^4S)6d\,^5D_{3,4}$
1	7061.56	14157.29	$(^2D)5s\,^3D_3-(^4S)8f\,^3F$
1	7056.27	14167.88	$(^4S)4d\,^5D_3-(^4S)11f\,^5F$
1	7049.15	14182.20	$(^4S)4d\,^5D_2-(^4S)11f\,^5F$
1	7047.55	14185.42	$(^4S)4d\,^5D_4-(^4S)11f\,^5F$
1	7043.15	14194.28	
1	7024.30	14232.36	
15	7013.85	14253.54	$(^4S)5p\,^5P_2-(^4S)6d\,^5D_2$
8	7012.75	14255.82	$(^4S)5p\,^5P_2-(^4S)6d\,^5D_1$
20	7010.82	14259.78	$(^4S)5p\,^5P_2-(^4S)6d\,^5D_3$
2	7002.84	14275.99	$(^2D)5s\,^3D_2-(^4S)9p\,^3P_1$
1	6998.47	14284.90	$(^2D)5s\,^3D_2-(^4S)9p\,^3P_2$
10	6991.77	14298.58	$(^4S)5p\,^5P_1-(^4S)6d\,^5D_2$
12	6990.65	14300.87	$(^4S)5p\,^5P_1-(^4S)6d\,^5D_1$
0	6973.33	14336.40	
2	6931.32	14423.29	$(^2D)5s\,^3D_1-(^4S)9p\,^3P_1$
1	6925.63	14435.13	
1	6905.76	14476.68	$(^4S)5p\,^3P_2-(^4S)7d\,^5D_1,\ (^2D)4d\ 2_1$
1	6899.91	14488.95	
2	6879.52	14531.88	$(^4S)5p\,^3P_1-(^4S)7d\,^5D_1,\ (^2D)4d\ 2_1$
2	6865.09	14562.44	$(^4S)5p\,^3P_0-(^2D)4d\ 2_1,\ (^4S)7d\,^5D_1$
1	6860.17	14572.88	$(^4S)5p\,^5P_2-(^4S)6d\,^3D_3$
1	6858.47	14576.49	$(^2D)5s\,^3D_2-(^4S)8f\,^3F$
1	6858.14	14577.19	$(^4S)5p\,^5P_1-(^4S)6d\,^3D_2$
1	6856.29	14581.12	$(^4S)5p\,^3P_2-(^2D)4d\ 2_1,\ (^4S)7d\,^5D_1$
15	6831.27	14634.54	$(^4S)5p\,^3P_2-(^4S)7d\,^3D_3$
6	6830.89	14635.35	$(^4S)5p\,^3P_2-(^4S)7d\,^3D_2$
2	6830.56	14636.06	$(^4S)5p\,^3P_1-(^2D)4d\ 2_1,\ (^4S)7d\,^5D_1$
5	6815.28	14668.86	$(^4S)5p\,^3P_0-(^4S)7d\,^3D_1$
8	6805.24	14690.50	$(^4S)5p\,^3P_1-(^4S)7d\,^3D_2$
0	6796.23	14709.97	
0	6789.93	14723.63	$(^2D)5s\,^3D_1-(^4S)8f\,^3F$
3	6781.22	14742.54	$(^4S)5p\,^3P_1-(^4S)7d\,^3D_1$
6	6768.50	14770.24	$(^4S)5p\,^5P_3-(^2D)4d\ 1_2,\ (^4S)8s\,^5S_2$
1	6757.12	14795.13	
0	6755.42	14798.85	
1	6748.73	14813.52	
8	6746.43	14818.56	$(^4S)5p\,^5P_3-(^4S)8s\,^5S_2,\ (^2D)4d\ 1_2$
1	6743.57	14824.85	
1	6737.46	14838.29	
5	6721.37	14873.80	$(^4S)5p\,^5P_2-(^2D)4d\ 1_2,\ (^4S)8s\,^5S_2$
0d	6708.45	14902.46	
0	6704.74	14910.70	
3	6701.04	14918.93	$(^4S)5p\,^5P_1-(^2D)4d\ 1_2,\ (^4S)8s\,^5S_2$
7	6699.56	14922.23	$(^4S)5p\,^5P_2-(^4S)8s\,^5S_2,\ (^2D)4d\ 1_2$
1	6690.67	14942.07	$(^4S)5p\,^3P_0-(^4S)9s\,^3S_1$
2	6682.36	14960.65	$(^4S)5p\,^3P_2-(^4S)9s\,^3S_1$
5	6679.43	14967.21	$(^4S)5p\,^5P_1-(^4S)8s\,^5S_2,\ (^2D)4d\ 1_2$
1	6666.69	14995.80	
2	6657.83	15015.75	$(^4S)5p\,^3P_1-(^4S)9s\,^3S_1$
1	6544.85	15274.98	
1	6512.69	15350.40	
5	6470.15	15451.32	$(^4S)5p\,^3P_2-(^4S)8d\,^3D_3,\ (^2D)4d\ 4_3$
1	6456.43	15484.17	$(^4S)5p\,^3P_2-(^4S)8d\,^5D_3$
3	6441.43	15520.22	$(^4S)5p\,^3P_0-(^4S)8d\,^3D_1$
1	6420.32	15571.25	$(^4S)5p\,^3P_2-(^4S)8d\,^3D_2$
2	6410.99	15593.90	$(^4S)5p\,^3P_1-(^4S)8d\,^3D_1$
4	6497.69	15626.30	$(^4S)5p\,^3P_1-(^4S)8d\,^3D_2$
2	6358.37	15722.95	$(^4S)5p\,^3P_2-(^2D)4d\ 4_3,\ (^4S)8d\,^3D_3$
1	6344.31	15757.82	$(^4S)5p\,^3P_2-(^4S)10s\,^3S_1$
0	6332.32	15787.63	
20	6325.57	15804.50	$(^4S)5p\,^5P_3-(^4S)7d\,^5D_{3,4}$
3	6325.11	15805.65	$(^4S)5p\,^5P_3-(^4S)7d\,^5D_2$
1	6322.21	15812.89	$(^4S)5p\,^3P_1-(^4S)10s\,^3S_1$
4	6300.99	15866.15	$(^4S)5p\,^5P_2-(^4S)7d\,^5D_1,\ (^2D)4d\ 2_1$
0	6295.32	15880.42	
10	6284.47	15907.86	$(^4S)5p\,^5P_2-(^4S)7d\,^5D_3$
9	6283.96	15909.14	$(^4S)5p\,^5P_2-(^4S)7d\,^5D_2$
8	6283.16	15911.16	$(^4S)5p\,^5P_1-(^4S)7d\,^5D_1,\ (^2D)4d\ 2_1$
6	6269.15	15946.73	
8	6266.23	15954.14	$(^4S)5p\,^5P_1-(^4S)7d\,^5D_2$
4	6259.81	15970.52	$(^4S)5p\,^5P_2-(^2D)4d\ 2_1,\ (^4S)7d\,^5D_1$
6	6242.21	16015.53	$(^4S)5p\,^5P_1-(^2D)4d\ 2_1,\ (^4S)7d\,^5D_1$
1	6220.86	16070.50	$(^4S)5p\,^3P_0-(^4S)9d\,^5D_1$
1	6216.57	16081.61	$(^4S)5p\,^3P_1-(^4S)9d\,^3D_1$
1	6207.78	16104.36	$(^4S)5p\,^3P_2-(^4S)9d\,^3D_2$
3	6207.20	16105.88	$(^4S)5p\,^3P_2-(^4S)9d\,^3D_3$
1	6203.27	16116.07	
1	6192.45	16144.24	$(^4S)5p\,^3P_1-(^4S)9d\,^5D_1$
1	6188.23	16155.25	$(^4S)5p\,^3P_1-(^4S)9d\,^3D_1$
2	6186.60	16159.51	$(^4S)5p\,^3P_1-(^4S)9d\,^3D_2$
6	6177.71	16182.76	$(^4S)5p\,^5P_3-(^4S)9s\,^5S_2$
5	6138.46	16286.23	$(^4S)5p\,^5P_2-(^4S)9s\,^5S_2$
4	6121.54	16331.24	$(^4S)5p\,^5P_1-(^4S)9s\,^5S_2$
8	5962.01	16768.23	$(^4S)5p\,^5P_3-(^4S)8d\,^5D_4$
1	5961.71	16769.07	$(^4S)5p\,^5P_3-(^4S)8d\,^5D_2$
5	5961.32	16770.17	$(^4S)5p\,^5P_3-(^4S)8d\,^5D_3$
2	5936.32	16840.81	$(^4S)5p\,^5P_2-(^4S)8d\,^3D_3,\ (^2D)4d\ 4_3$
5	5925.15	16872.54	$(^4S)5p\,^5P_2-(^4S)8d\,^5D_2$
1	5924.98	16873.03	$(^4S)5p\,^5P_2-(^4S)8d\,^5D_1$
6	5924.76	16873.67	$(^4S)5p\,^5P_2-(^4S)8d\,^5D_3$
4	5909.38	16917.58	$(^4S)5p\,^5P_1-(^4S)8d\,^5D_2$
5	5909.20	16918.08	$(^4S)5p\,^5P_1-(^4S)8d\,^5D_1$
3	5907.08	16924.16	
3	5878.70	17005.86	$(^4S)5p\,^5P_3-(^4S)10s\,^5S_2$
2	5843.14	17109.36	$(^4S)5p\,^5P_2-(^4S)10s\,^5S_2$
2	5827.80	17154.38	$(^4S)5p\,^5P_1-(^4S)10s\,^5S_2$
4	5753.32	17376.46	$(^4S)5p\,^5P_3-(^4S)9d\,^5D_4$
2	5752.03	17380.37	$(^4S)5p\,^5P_3-(^4S)9d\,^5D_3$
3	5738.29	17421.99	
1	5719.68	17478.65	$(^4S)5p\,^5P_2-(^4S)9d\,^5D_1$
2	5718.43	17482.49	$(^4S)5p\,^5P_2-(^4S)9d\,^5D_2$
3	5717.99	17483.82	$(^4S)5p\,^5P_2-(^4S)9d\,^5D_3$
2	5704.98	17523.71	$(^4S)5p\,^5P_1-(^4S)9d\,^5D_1$
3	5703.73	17527.53	$(^4S)5p\,^5P_1-(^4S)9d\,^5D_2$
1	5703.11	17529.44	
2	5702.44	17531.50	
2	5701.37	17534.78	$(^4S)5p\,^5P_1-(^4S)\ 9d\,^3D_1$
2	5700.24	17538.28	$(^4S)5p\,^5P_3-(^4S)11s\,^5S_2$
1	5666.80	17641.76	$(^4S)5p\,^5P_2-(^4S)11s\,^5S_2$
1	5652.36	17686.82	$(^4S)5p\,^5P_1-(^4S)11s\,^5S_2$
1	5618.92	17792.09	$(^4S)5p\,^5P_3-(^4S)10d\,^5D_3$
3	5617.87	17795.41	$(^4S)5p\,^5P_3-(^4S)10d\,^5D_4$
2	5586.43	17895.58	$(^4S)5p\,^5P_2-(^4S)10d\,^5D_3$
1	5586.34	17895.87	$(^4S)5p\,^5P_2-(^4S)10d\,^5D_2$
1	5572.31	17940.92	$(^4S)5p\,^5P_1-(^4S)10d\,^5D_2$
1	5572.22	17941.21	$(^4S)5p\,^5P_1-(^4S)10d\,^5D_1$
1	5530.28	18082.28	$(^4S)5p\,^5P_3-(^4S)11\mathrm{d}\,^5D_3$
2	5530.12	18082.80	$(^4S)5p\,^5P_3-(^4S)11d\,^5D_4$
1d	5499.48	18183.55	$(^4S)5p\,^5P_2-(^4S)11d\,^5D_{1,2}$
2	5498.78	18185.83	$(^4S)5p\,^5P_2-(^4S)11d\,^5D_3$
11	5374.14	18602.46	$(^4S)5s\,^3S_1-(^4S)6p\,^3P_1$
12	5369.91	18617.14	$(^4S)5s\,^3S_1-(^4S)6p\,^3P_2$
10	5365.47	18632.54	$(^4S)5s\,^3S_1-(^4S)6p\,^3P_0$
6	4886.99	20456.78	$4p^4\,^3P_1-4p^4\,^1S_0$
3	4792.73	20859.11	$(^4S)5s\,^3S_1-(^2D)5p\,^3D_1$
30	4742.25	21081.16	$(^4S)5s\,^5S_2-(^4S)6p\,^5P_1$
40	4739.03	21095.49	$(^4S)5s\,^5S_2-(^4S)6p\,^5P_2$
50	4730.78	21132.29	$(^4S)5s\,^5S_2-(^4S)6p\,^5P_3$
6	4667.80	21417.41	$(^4S)5s\,^5S_2-(^4S)6p\,^3P_1$
8	4664.98	21430.36	$(^4S)5s\,^3S_1-(^2D)5p\,^3D_2$
10	4664.20	21431.99	$(^4S)5s\,^5S_2-(^4S)6p\,^3P_2$
8	4623.77	21621.35	$(^4S)5s\,^3S_1-(^2D)5p\,^3F_2$
1	4571.36	21869.24	$(^4S)5s\,^3S_1-(^2D)5p\,^1P_1$
1	4534.89	22045.08	$(^4S)5s\,^3S_1-(^4S)7p\,^3P_0$
2	4534.68	22046.11	$(^4S)5s\,^3S_1-(^4S)7p\,^3P_1$
3	4532.74	22055.55	$(^4S)5s\,^3S_1-(^4S)7p\,^3P_2$
8	4339.59	23037.22	$(^4S)5s\,^3S_1-(^2D)5p\,^3P_0$
10	4330.28	23086.73	$(^4S)5s\,^3S_1-(^2D)5p\,^3P_1$
12	4328.70	23095.17	$(^4S)5s\,^3S_1-(^2D)5p\,^3P_2$
2	4184.08	23893.40	
2	4141.17	24140.97	$(^4S)5s\,^3S_1-(^4S)8p\,^3P_0$
3	4140.40	24145.44	$(^4S)5s\,^3S_1-(^4S)8p\,^3P_1$
4	4139.66	24149.82	$(^4S)5s\,^3S_1-(^4S)8\mathrm{p}\,^3P_2$
2	4111.88	24312.93	$(^4S)5s\,^3S_1-(^2D)5p\,^1D_2$
4	4023.23	24848.68	$(^4S)5s\,^5S_2-(^2D)5p\,^3D_3$
3	4021.26	24860.85	$(^4S)5s\,^5S_2-(^4S)7p\,^3P_1$
4	4019.72	24870.33	$(^4S)5s\,^5S_2-(^4S)7p\,^3P_2$
6	4014.77	24901.04	$(^4S)5s\,^5S_2-(^4S)7p\,^5P_1$
8	4012.96	24912.27	$(^4S)5s\,^5S_2-(^4S)7p\,^5P_2$
10	4011.88	24918.98	$(^4S)5s\,^5S_2-(^4S)7p\,^5P_3$
1	3985.83	25081.79	$(^4S)5s\,^5S_2-(^2D)5p\,^1F_3$
1	3981.74	25107.55	$(^4S)5s\,^3S_1-(^4S)9p\,^3P_1$
1	3980.34	25116.38	$(^4S)5s\,^3S_1-(^4S)9p\,^3P_2$
1	3735.02	26766.04	$(^4S)5s\,^5S_2-(^4S)8p\,^5P_1$
2	3734.50	26769.73	$(^4S)5s\,^5S_2-(^4S)8p\,^5P_2$
3	3733.34	26778.11	$(^4S)5s\,^5S_2-(^4S)8p\,^5P_3$
1	3592.01	27831.74	$(^4S)5s\,^5S_2-(^4S)9p\,^5P_1$
1	3591.66	27834.45	$(^4S)5s\,^5S_2-(^4S)9p\,^5P_2$
2	3591.03	27839.33	$(^4S)5s\,^5S_2-(^4S)9p\,^5P_3$
5	3501.52	28550.90	$4p^4\,^1S_0-(^4S)5s\,^3S_1$
30	2547.98	39235.1	$4p^4\,^1S_0-(^2D)5s\,^3D_1$
4	2442.07	40936.5	$4p^4\,^1S_0-(^4S)4d\,^5D_1$
60	2413.517	41420.71	$4p^4\,^1D_2-(^4S)5s\,^3S_1$
15	2332.81	42853.7	$4p^4\,^1S_0-(^4S)4d\,^3D_1$
50	2164.160	46192.75	$4p^4\,^3P_1-(^4S)5s\,^5S_2$

TABLE I.—*Continued.*

Int.	λ(air)	ν(vac)	Transition
6	2147.19	46557.8	
8	2081.08	48036.5	
50	2074.793	48182.14	$4p^4\ ^3P_2-(^4S)5s\ ^5S_2$
40	2062.788	48462.50	$4p^4\ ^3P_0-(^4S)5s\ ^3S_1$
4	2054.36	48661.3	$4p^4\ ^1S_0-(^4S)5d\ ^3D_1$
6	2050.43	48754.6	$4p^4\ ^1S_0-(^2P)5s\ ^3P_1$
50	2039.851	49007.38	$4p^4\ ^3P_1-(^4S)5s\ ^3S_1$
4	2021.80	49445.0	$4p^4\ ^1S_0-(^4S)7s\ ^3S_1$
15	1994.47	50122.5	$4p^4\ ^1S_0-(^2P)5s\ ^1P_1$
50	1960.257	50996.97	$4p^4\ ^3P_2-(^4S)5s\ ^3S_1$
30	1918.552	52105.32	$4p^4\ ^1D_2-(^2D)5s\ ^3D_1$
35	1913.151	52252.39	$4p^4\ ^1D_2-(^2D)5s\ ^3D_2$
40	1897.921	52671.64	$4p^4\ ^1D_2-(^2D)5s\ ^3D_3$

Int.	λ(vac)	ν(vac)	Transition
6	1893.50	52812.3	$4p^4\ ^1S_0-(^2D)4d\ 2_1,\ (^4S)7d\ ^5D_1$
5	1859.69	53772.4	
25	1858.84	53797.0	$4p^4\ ^1D_2-(^4S)4d\ ^5D_2$
30	1855.20	53902.5	$4p^4\ ^1D_2-(^2D)5s\ ^1D_2$
3	1852.02	53995.1	
3	1850.51	54039.2	
4	1849.55	54067.2	
4	1830.41	54632.6	
3	1828.65	54685.2	
8	1822.15	54880.2	
6	1796.04	55678.0	
30	1795.28	55701.6	$4p^4\ ^1D_2-(^4S)4d\ ^3D_2$
5	1794.55	55724.3	$4p^4\ ^1D_2-(^4S)4d\ ^3D_1$
25	1793.29	55763.4	$4p^4\ ^1D_2-(^4S)4d\ ^3D_3$
3	1790.48	55850.9	
5	1772.64	56413.0	$4p^4\ ^1D_2-(^4S)6s\ ^5S_2$
8	1759.24	56842.7	
6	1752.94	57047.0	$4p^4\ ^1D_2-(^4S)6s\ ^3S_1$
3	1751.88	57081.5	
6	1750.89	57113.8	
3	1745.30	57296.7	
4	1742.75	57380.6	
3	1708.04	58546.6	
2	1706.70	58592.6	
4	1699.90	58827.0	
25	1690.70	59147.1	$4p^4\ ^3P_0-(^2D)5s\ ^3D_1$
3	1688.79	59214.0	
25	1675.27	59691.9	$4p^4\ ^3P_1-(^2D)5s\ ^3D_1$
25	1671.15	59839.0	$4p^4\ ^3P_1-(^2D)5s\ ^3D_2$
15	1643.39	60849.8	$4p^4\ ^3P_0-(^4S)4d\ ^5D_1$
1	1635.80	61132.2	
6	1629.06	61385.1	$4p^4\ ^3P_1-(^4S)4d\ ^5D_2$
8	1628.85	61393.0	$4p^4\ ^3P_1-(^4S)4d\ ^5D_{0,1}$
12	1626.25	61491.2	$4p^4\ ^3P_1-(^4S)5s\ ^1D_2$
6	1625.45	61521.4	$4p^4\ ^1D_2-(^4S)5d\ ^3D_2$
7	1625.19	61531.3	$4p^4\ ^1D_2-(^4S)5d\ ^3D_1$
5	1623.90	61580.1	$4p^4\ ^1D_2-(^4S)5d\ ^3D_3$
10	1622.73	61624.5	$4p^4\ ^1D_2-(^2P)5s\ ^3P_1$
15	1621.21	61682.3	$4p^4\ ^3P_2-(^2D)5s\ ^3D_1$
20	1617.35	61829.5	$4p^4\ ^3P_2-(^2D)5s\ ^3D_2$
10	1611.26	62063.2	$4p^4\ ^1D_2-(^4S)7s\ ^5S_2,\ (^2P)5s\ ^3P_2$
10	1610.72	62084.0	$4p^4\ ^1D_2-(^2P)5s\ ^3P_2,\ (^4S)7s\ ^5S_2$
25	1606.46	62248.7	$4p^4\ ^3P_2-(^2D)5s\ ^3D_3$
4	1604.70	62316.9	$4p^4\ ^1D_2-(^4S)7s\ ^3S_1$
15	1593.19	62767.2	$4p^4\ ^3P_0-(^4S)4d\ ^3D_1$
15	1587.46	62993.7	$4p^4\ ^1D_2-(^2P)5s\ ^1P_1$
20	1580.04	63289.5	$4p^4\ ^3P_1-(^4S)4d\ ^3D_2$
15	1579.49	63311.6	$4p^4\ ^3P_1-(^4S)4d\ ^3D_1$
15	1577.90	63375.4	$4p^4\ ^3P_2-(^4S)4d\ ^5D_2$
15	1577.61	63387.0	$4p^4\ ^3P_2-(^4S)4d\ ^5D_{1,3}$
15	1575.26	63481.6	$4p^4\ ^3P_2-(^2D)5s\ ^1D_2$
2	1563.28	63968.1	$4p^4\ ^1D_2-(^4S)6d\ ^5D_{1,2,3}$
2	1562.50	64000.0	$4p^4\ ^3P_1-(^4S)6s\ ^5S_2$
12	1560.28	64091.1	$4p^4\ ^3P_0-(^4S)6s\ ^3S_1$
1	1556.54	64245.1	$4p^4\ ^1D_2-(^4S)6d\ ^3D_2$
4	1555.55	64285.9	$4p^4\ ^1D_2-(^4S)6d\ ^3D_{1,3}$
8	1548.29	64587.4	$4p^4\ ^1D_2-(^2D)4d\ 1_2,\ (^4S)8s\ ^5S_2$

Int.	λ(vac)	ν(vac)	Transition
12	1547.12	64636.2	$4p^4\ ^3P_1-(^4S)6s\ ^3S_1$
20	1531.84	65281.0	$4p^4\ ^3P_2-(^4S)4d\ ^3D_2$
15	1531.33	65302.7	$4p^4\ ^3P_2-(^4S)4d\ ^3D_1$
25	1530.39	65342.8	$4p^4\ ^3P_2-(^4S)4d\ ^3D_3$
6	1524.88	65578.9	$4p^4\ ^1D_2-(^4S)7d\ ^5D_1,\ (^2D)4d\ 2_1$
6	1522.45	65683.6	$4p^4\ ^1D_2-(^2D)4d\ 2_1,\ (^4S)7d\ ^5D_1$
3	1521.20	65737.6	$4p^4\ ^1D_2-(^4S)7d\ ^3D_{2,3}$
4	1519.99	65789.9	$4p^4\ ^1D_2-(^4S)7d\ ^3D_1$
8	1515.33	65992.2	$4p^4\ ^3P_2-(^4S)6s\ ^5S_2$
2	1511.27	66169.5	
3	1506.09	66397.1	$4p^4\ ^1D_2-(^2D)4d\ 3_2$
2	1502.57	66552.6	$4p^4\ ^1D_2-(^4S)8\mathrm{d}\ ^3D_3,\ (^2D)4d\ 4_3$
15	1500.91	66626.2	$4p^4\ ^3P_2-(^4S)6s\ ^3S_1$
3	1496.44	66825.3	$4p^4\ ^1D_2-(^2D)4d\ 4_3,\ (^4S)8d\ ^3D_3$
6	1461.99	68399.9	$4p^4\ ^3P_1-(^4S)5d\ ^5D_{1,2}$
8	1458.29	68573.5	$4p^4\ ^3P_0-(^4S)5d\ ^3D_1$
12	1456.31	68666.7	$4p^4\ ^3P_0-(^2P)5s\ ^3P_1$
15	1449.16	69005.5	$4p^4\ ^3P_1-(^2P)5s\ ^3P_0$
10	1446.98	69109.5	$4p^4\ ^3P_1-(^4S)5d\ ^3D_2$
10	1446.78	69119.0	$4p^4\ ^3P_1-(^4S)5d\ ^3D_1$
10	1444.85	69211.3	$4p^4\ ^3P_1-(^2P)5s\ ^3P_1$
5	1441.81	69357.3	$4p^4\ ^3P_0-(^4S)7s\ ^3S_1$
12	1435.75	69650.0	$4p^4\ ^3P_1-(^4S)7s\ ^5S_2,\ (^2P)5s\ ^3P_2$
12	1435.28	69672.8	$4p^4\ ^3P_1-(^2P)5s\ ^3P_2,\ (^4S)7s\ ^5S_2$
6	1430.58	69901.7	$4p^4\ ^3P_1-(^4S)7s\ ^3S_1$
6	1427.87	70034.4	$4p^4\ ^3P_0-(^2P)5s\ ^1P_1$
5	1426.68	70092.8	
8	1420.64	70390.8	$4p^4\ ^3P_2-(^4S)5d\ ^5D_{1,2,3}$
8	1416.84	70579.6	$4p^4\ ^3P_1-(^2P)5s\ ^1P_1$
3	1414.26	70708.4	
10	1406.60	71093.4	$4p^4\ ^3P_2-(^4S)5d\ ^3D_2$
10	1406.37	71105.0	$4p^4\ ^3P_2-(^4S)5d\ ^3D_1$
10	1405.37	71155.6	$4p^4\ ^3P_2-(^4S)5d\ ^3D_3$
8	1404.45	71202.2	$4p^4\ ^3P_2-(^2P)5s\ ^3P_1$
1	1402.63	71294.6	
4	1401.92	71330.7	$4p^4\ ^3P_0-(^4S)6d\ ^3D_1$
2	1397.49	71556.9	$4p^4\ ^3P_1-(^4S)6d\ ^5D_{1,2}$
10	1395.88	71639.4	$4p^4\ ^3P_2-(^4S)7s\ ^5S_2,\ (^2P)5s\ ^3P_2$
10	1395.43	71662.5	$4p^4\ ^3P_2-(^2P)5s\ ^3P_2,\ (^4S)7s\ ^5S_2$
4	1392.97	71789.1	$4p^4\ ^3P_0-(^4S)8s\ ^3S_1$
5	1392.13	71832.4	$4p^4\ ^3P_1-(^4S)6d\ ^3D_2$
4	1391.27	71876.8	$4p^4\ ^3P_1-(^4S)6d\ ^3D_{1,3}$
6	1390.99	71891.2	$4p^4\ ^3P_2-(^4S)7s\ ^3S_1$
8	1385.54	72174.0	$4p^4\ ^3P_1-(^2D)4d\ 1_2,\ (^4S)8s\ ^5S_2$
2	1384.63	72221.5	$4p^4\ ^3P_1-(^4S)8s\ ^5S_2,\ (^2D)4d\ 1_2$
3	1382.56	72329.6	$4p^4\ ^3P_1-(^4S)8s\ ^3S_1$
0	1379.50	72490.0	
10	1377.98	72570.0	$4p^4\ ^3P_1-(^2P)5s\ ^1P_1$
2	1377.04	72619.5	$4p^4\ ^3P_0-(^4S)7d\ ^5D_1,\ (^2D)4d\ 2_1$
2	1375.03	72725.7	$4p^4\ ^3P_0-(^2D)4d\ 2_1,\ (^4S)7d\ ^5D_1$
2	1373.03	72831.6	$4p^4\ ^3P_0-(^4S)7d\ ^3D_1$
0	1367.91	73104.2	$4p^4\ ^3P_0-(^4S)9s\ ^3S_1$
1	1366.78	73164.7	$4p^4\ ^3P_1-(^4S)7d\ ^5D_1,\ (^2D)4d\ 2_1$
3	1364.83	73269.2	$4p^4\ ^3P_1-(^2D)4d\ 2_1,\ (^4S)7d\ ^5D_1$
1	1363.80	73324.5	$4p^4\ ^3P_1-(^4S)7d\ ^3D_2$
3	1359.72	73544.6	$4p^4\ ^3P_2-(^4S)6d\ ^5D_{1,2,3}$
0	1357.79	73649.1	$4p^4\ ^3P_1-(^4S)9s\ ^3S_1$
5	1354.63	73820.9	$4p^4\ ^3P_2-(^4S)6d\ ^3D_2$
7	1353.86	73862.9	$4p^4\ ^3P_2-(^4S)6d\ ^3D_{1,3}$
7	1353.02	73908.7	
4	1351.62	73985.3	$4p^4\ ^3P_1-(^2D)4d\ 3_2$
5	1348.40	74162.0	$4p^4\ ^3P_2-(^2D)4d\ 1_2,\ (^4S)8s\ ^5S_2$
1	1347.50	74211.5	$4p^4\ ^3P_2-(^4S)8s\ ^5S_2,\ (^2D)4d\ 1_2$
0	1346.58	74262.2	
4	1345.54	74319.6	$4p^4\ ^3P_2-(^4S)8s\ ^3S_1$
4	1342.04	74513.4	
4	1330.55	75156.9	$4p^4\ ^3P_2-(^4S)7d\ ^5D_1,\ (^2D)4d\ 2_1$
4	1328.75	75258.7	$4p^4\ ^3P_2-(^2D)4d\ 2_1,\ (^4S)7d\ ^5D_1$
1	1327.80	75312.5	$4p^4\ ^3P_2-(^4S)7d\ ^3D_{2,3}$
2	1326.83	75367.6	$4p^4\ ^3P_2-(^4S)7d\ ^3D_1$
1	1322.06	75639.5	$4p^4\ ^3P_2-(^4S)9s\ ^3S_1$
3	1316.26	75972.8	$4p^4\ ^3P_2-(^2D)4d\ 3_2$
3	1313.53	76130.7	$4p^4\ ^3P_2-(^4S)8d\ ^3D_3,\ (^2D)4d\ 4_3$

but there still remain 119 weak ones which have not been identified as impurities and for which no place has been found in the term scheme so far developed.

Table I lists all the observed wave-lengths, intensities (comparable only over short ranges), wave numbers and transition designations. In cases where one of the terms involved is the result of a recognized perturbation between two configurations, both designations are given, with the predominant one first. Some incompletely assigned terms are indicated by numbers with J subscripts as determined by their apparent combining properties. A d after the intensity number means the line was diffuse.

The transitions involving the five $4p^4$ terms

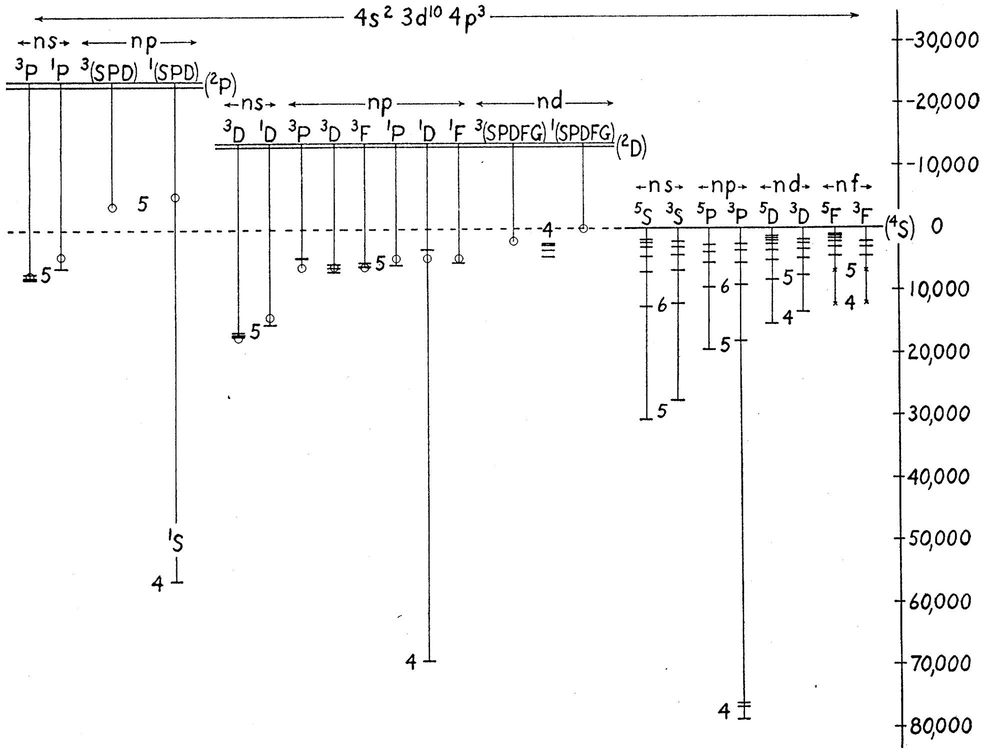

FIG. 1. Energy levels of Se I.

are open to almost no other interpretation. All are observed that would be expected due to combinations with $4p^3ns$ and $4p^3nd$ terms and no intense lines are left over. The $4s$ electron is not excited to any extent as the $2s$ and $3s$ electrons are in oxygen and sulfur. Long wave-length combinations and series relations serve to check most of the assignments, and analogies with oxygen and sulfur are well maintained in relative positions of terms. Intercombinations are quite strong and the L selection rule is commonly violated, which gives ample check on the choice of the $4p^4\ {}^1D_2$ and ${}^1S_0$ terms.

An analysis of Se II being carried out in this laboratory at the present time has established the relative positions of the low ${}^4S$, ${}^2D$, and ${}^2P$ terms which are the limits of the Se I series. The positions of the terms built on the doublet limits can be roughly predicted, as was done in the cases of oxygen[10] and sulfur,[4] by assuming that the energy of interaction of the excited electron and the atom core is independent of the state of the core. These positions are marked in Fig. 1 by the circles, and in every case where they lie below the ${}^4S$ limit, groups of terms are found having the appropriate combining properties. The atom would be expected to have such a short life in those states which lie above the ${}^4S$ limit (due to the auto-ionization effect[11]) that their combinations would not be observed. Fig. 1 indicates by short horizontal lines the known terms arranged in series. Crosses mark the approximate positions for the first and second members of the ${}^5F$ and ${}^3F$ series, which have not been located due to their unfavorable positions for observable combinations.

The two series $({}^4S)5p\ {}^5P_{123}-({}^4S)ns\ {}^5S_2$ and $({}^4S)5p\ {}^5P_3-({}^4S)nd\ {}^5D_4$ were accurately measured to seven and nine members respectively and the limits obtained agree with each other and with those given by Runge and Paschen[5] within about one wave number. The method used for deter-

[10] R. Frerichs, Phys. Rev. **34**, 1239 (1929).

[11] A. G. Shenstone, Phys. Rev. **38**, 873 (1931).

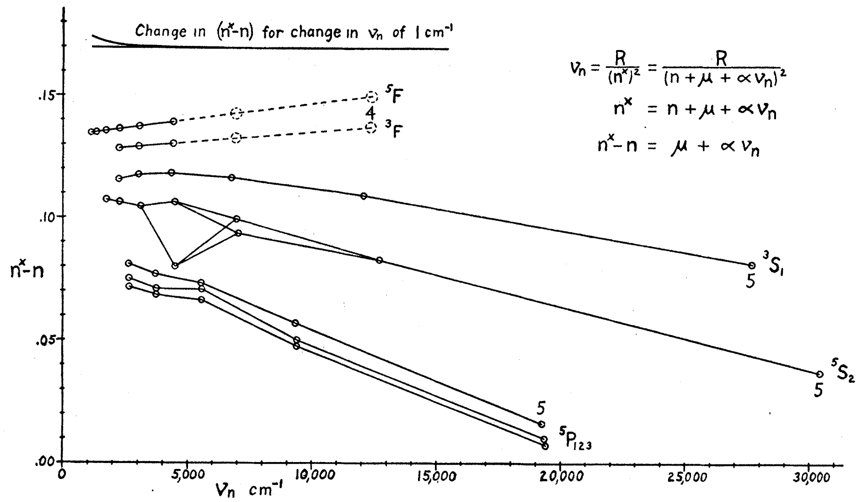

FIG. 2. Series in Se I.

mining limits was that recommended by Shenstone and Russell;[12] namely, plotting quantum defect against term value. The presence of perturbations is thus also clearly brought out, and these are found to be of quite frequent occurrence in selenium.

A new series of ^5F terms was obtained from the combination $(^4S)4d\ ^5D_{01234}-(^4S)nf\ ^5F$ for $n=6\cdots 11$. The plot of this series (Fig. 2) shows no perturbations and it was possible to determine its limit within 0.2 cm^{-1}, as illustrated by the "sensitivity curve" at the top of the figure. Ample combinations were found with these accurately established terms to permit all the rest of the term scheme to be brought to the same absolute accuracy, excepting only five levels which are determined solely from the vacuum spectrograph measurements.

The plots of quantum defect *vs.* term value for all the series built on the (^4S) limit are shown in Figs. 2, 3 and 4. The quantity (n^*-n), which is plotted here, is actually the negative of the quantum defect. The point of origin on the ordinate scale is arbitrarily chosen and, in general, differs by different amounts from the true origin for each series. Within each of the multiplets $^5P_{123}$, $^3P_{012}$, and $^3D_{123}$, however, the origin is the same. The members of the $^5D_{1234}$ multiplet have been arbitrarily separated by amounts indicated by the darts. In a number of cases there are two terms which fit almost equally well as members of the series and both are plotted. In the $^5S_2$ series the perturbing terms for $n=7$ and 8 are $(^2P)5s\ ^3P_2$ and $(^2D)4d\ 1_2$. In the $^5D_1$ series the perturbing term for $n=7$ is $(^2D)4d\ 2_1$. In the $^3D_3$ series the perturbing term for $n=8$ is $(^2D)4d\ 4_3$. The $^3P_{012}$ series experiences a very strong perturbation due to the term $(^2D)5p\ ^3P_{012}$, which lies between members 7 and 8. The causes of the other series irregularities cannot be definitely fixed. The eighteen levels arising from the $(^2D)4d$ configuration should lie within a few thousand wave numbers of the (^4S) limit and others of these, besides the three just mentioned, may be producing disturbances of lesser extent.

Transitions between terms built on different states of the ion are "double electron jumps" and do not occur unless there is some form of coupling which makes possible such a simultaneous change. Such coupling is described as a mutual perturbation of two (or more) energy levels and can be accurately described only on the basis of wave mechanics.[13, 14, 15, 16] The necessary conditions for the occurrence of a perturbation

[12] A. G. Shenstone and H. N. Russell, Phys. Rev. **39**, 415 (1932).

[13] E. U. Condon, Phys. Rev. **36**, 1121 (1930).

[14] S. Goudsmit and L. Gropper, Phys. Rev. **38**, 225 (1931).

[15] N. G. Whitelaw, Phys. Rev. **44**, 544 (1933).

[16] J. H. Van Vleck and N. G. Whitelaw, Phys. Rev. **44**, 551 (1933).

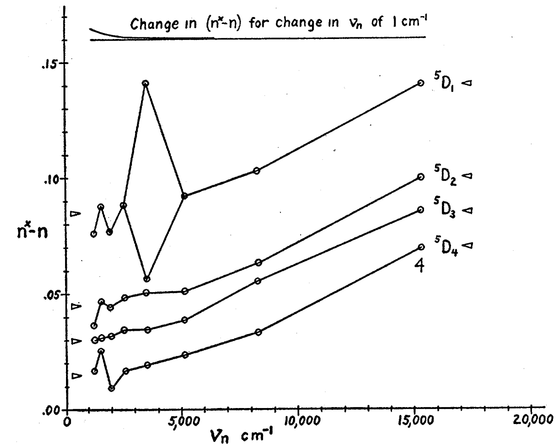

FIG. 3. Series in Se I.

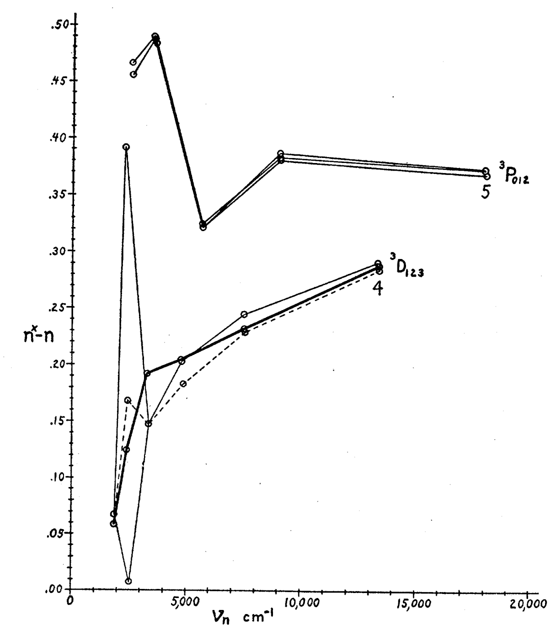

FIG. 4. Series in Se I.

between two terms in the case of LS coupling have been given by Shenstone and Russell[12] and are that they shall have parity (both odd or both even), the same J, the same L, and the same S, and generally the closer the terms the greater is the effect. However, it has been shown by Whitelaw[15] that closeness is not a necessary condition for a large effect. In selenium the coupling is not good LS and the perturbation conditions are relaxed in regard to equality of L's and S's.

In addition to the effect on the combining properties, perturbations also cause shifts in the terms involved as if there was a repulsion between them. It is to this effect that the anomalous positions of terms and partial inversions of multiplets, which are so common in selenium, are ascribed. In most cases the absolute magnitude of the displacement of a term is small and no near neighbor of the right type is at hand to accept the blame. In many cases there are undoubtedly more than two terms entering into a perturbation.

It is here suggested that the combination of the $(^4S)nf\ ^5F$ and ^3F terms with the $(^2D)5s\ ^3D$ and ^1D terms is due to perturbations of the latter by the $(^4S)4d\ ^5D$ and ^3D terms. The arc spectrum of sulfur exhibits the same peculiarities as that of selenium, and in particular the terms $(^4S)nf\ ^5F$ and ^3F were found to combine with the $(^2D)5s\ ^3D$ terms, as designated by Frerichs.[17] In a later paper on sulfur Meissner, Bartelt and Eckstein[18] objected to the $s\rightarrow f$ electron transition and interchanged the terms $(^2D)5s\ ^3D$ and $(^4S)4d\ ^3D$, although this gave the ^3D terms built on the single limit a considerably greater separation than those built on the double limit, and also seriously disturbed the agreement of the $(^2D)5s\ ^3D$ terms with their expected positions, as discussed by Ruedy.[4] We prefer the designations of Frerichs and the explanation involving perturbations, especially as the analogous alternative in selenium would lead to even greater discrepancies in separations and positions than it did in sulfur.

The terms due to the addition of the $5s$ electron to the (^2D) and (^2P) cores all combine strongly with the $4p^4$ levels. Each triplet has an outer separation somewhat smaller than its doublet limit separation and each singlet lies about the same distance above its corresponding triplet. The terms built on the (^2D) limit are also confirmed by other combinations. The $(^2P)5s\ ^3P_2$ term and the $(^4S)7s\ ^5S_2$ term perturb each other to such an extent as to make their individual designations nearly meaningless. The $(^2P)5s\ ^3P_{0,1}$ and $^1P_1$ terms show no other trustworthy com-

[17] R. Frerichs, Zeits. f. Physik **80**, 150 (1933).
[18] K. W. Meissner, O. Bartelt and E. Eckstein, Zeits. f. Physik **86**, 54 (1933).

binations but rely, for their identification, upon the considerations just stated and the fact that all the strong lines are thus accounted for.

Twelve levels are located in the neighborhood of the predicted positions for the $(^2D)5p$ terms, and their relative positions and combining properties, aided by certain of their perturbation effects, seem to justify the assignment of definite L and S values. Just three of these terms combine strongly with the $(^2D)5s\ ^1D_2$ and $(^4S)4d\ ^5D_2$ terms which are evidently perturbing one another. They are accordingly called the singlets, and the J selection rule permits but one possible designation for them. The three levels $(^2D)5p\ ^3P_{012}$ are unquestionably responsible for the great perturbation of the $(^4S)np\ ^3P_{012}$ series. It is not necessary that the levels with $J=1$ and 2 should be ^3P's but the term with $J=0$ is unique and otherwise to form a ^3P multiplet would spread it and the other multiplets in a much more erratic manner. Also the magnitude of the perturbations due to these three levels are nearly the same and are all much greater than any of the other perturbations observed. This is very reasonably explained on the basis that, although the equality of L's and S's of perturbing terms is not a necessity, such equality is conducive to a larger effect than would otherwise be the case. The level with $J=4$ is also unique, and the remaining triplet terms can be unambiguously designated from their combining intensities.

Four of the group of eighteen terms due to the configuration $(^2D)4d$ have been observed, and three of them show intimate sharing of their configurations with certain $(^4S)ns$ and nd terms. It is possible to assign only J values to these. Without such perturbations none of these terms would combine with any of those built on the

TABLE II. *Se I terms.*

$4s^2$ $3d^{10}$ $4p^3$	$4p$	$^3P_2$: 78658.22 $^3P_1$: 76668.73 $^3P_0$: 76123.87	$^1D_2$: 69082.14	$^1S_0$: 56212.19
		Limit $^4S_{3/2}$: 0	Limit $^2D_{3/2}$: −13164 $^2D_{5/2}$: −13780	Limit $^2P_{1/2}$: −23032 $^2P_{3/2}$: −23890
	$5s$	$^5S_2$: 30476.03 $^3S_1$: 27661.29	$^3D_1$: 16976.91 $^3D_2$: 16829.70 $^3D_3$: 16410.60 $^1D_2$: 15178.91	$^3P_0$: 7663.2 $^3P_1$: 7458.6 $^3P_2$: 6999.20(1) $^1P_1$: 6089.66
	$5p$	$^5P_1$: 19415.34 $^5P_2$: 19370.31 $^5P_3$: 19266.84 $^3P_1$: 18035.85 $^3P_2$: 17980.76 $^3P_0$: 17962.15	$^3D_1$: 6802.13 $^3D_2$: 6230.91 $^3F_2$: 6039.93 $^3F_3$: 5941.60 $^1P_1$: 5792.01 $^3D_3$: 5627.29 $^3F_4$: 5404.12 $^1F_3$: 5394.19 $^3P_0$: 4624.16 $^3P_1$: 4574.65 $^3P_2$: 4566.12 $^1D_2$: 3348.34	—
	$4d$	$^5D_4$: 15288.15 $^5D_2$: 15285.03 $^5D_0$: 15277.38 $^5D_1$: 15275.48 $^5D_3$: 15270.76 $^3D_2$: 13380.26 $^3D_1$: 13358.78 $^3D_3$: 13318.50	1_2: 4496.52(2) 2_1: 3399.75(3) 3_2: 2684.6 4_3: 2257.81(4) —	—

	Limit $^4S_{3/2}$: 0
$6s$	$^5S_2$: 12669.1 $^3S_1$: 12035.1
$6p$	$^5P_1$: 9394.77 $^5P_2$: 9380.44 $^5P_3$: 9343.64 $^3P_1$: 9058.73 $^3P_2$: 9044.15 $^3P_0$: 9028.75
$5d$	$^5D_0$: — $^5D_1$: 8269.66 $^5D_2$: 8269.16 $^5D_4$: 8267.18 $^5D_3$: 8266.50 $^3D_2$: 7561.98 $^3D_1$: 7551.97 $^3D_3$: 7503.26
$7s$	$^5S_2$: 7019.94(1) $^3S_1$: 6767.89
$7p$	$^3P_0$: 5616.17 $^3P_1$: 5615.18 $^3P_2$: 5605.67 $^5P_1$: 5574.99 $^5P_2$: 5563.80 $^5P_3$: 5557.02
$6d$	$^5D_0$: — $^5D_2$: 5116.80 $^5D_1$: 5114.54 $^5D_3$: 5110.66 $^5D_4$: 5110.5 $^3D_2$: 4838.23 $^3D_3$: 4797.54 $^3D_1$: 4794.34

	Limit $^4S_{3/2}$: 0
$8s$	$^5S_2$: 4448.16(2) $^3S_1$: 4340.02
$6f$	^5F: 4425.75 ^3F: 4423.64
$8p$	$^5P_1$: 3709.99 $^5P_2$: 3706.30 $^5P_3$: 3697.92 $^3P_0$: 3520.33 $^3P_1$: 3515.90 $^3P_2$: 3511.51
$7d$	$^5D_0$: — $^5D_1$: 3504.10(3) $^5D_3$: 3462.45 $^5D_4$: 3462.5 $^5D_2$: 3461.19 $^3D_3$: 3346.22 $^3D_2$: 3345.38 $^3D_1$: 3293.30
$9s$	$^5S_2$: 3084.08 $^3S_1$: 3020.10
$7f$	^5F: 3070.97 ^3F: 3069.30
$9p$	$^5P_1$: 2644.29 $^5P_2$: 2641.58 $^5P_3$: 2636.70 $^3P_0$: — $^3P_1$: 2553.69 $^3P_2$: 2544.86

	Limit $^4S_{3/2}$: 0
$8d$	$^3D_3$: 2529.44(4) $^5D_0$: — $^5D_4$: 2498.61 $^5D_2$: 2497.77 $^5D_1$: 2497.27 $^5D_3$: 2496.63 $^3D_1$: 2441.94 $^3D_2$: 2409.53
$10s$	$^5S_2$: 2260.96 $^3S_1$: 2222.95
$8f$	^5F: 2254.54 ^3F: 2253.33
$9d$	$^5D_0$: — $^5D_1$: 1891.64 $^5D_4$: 1890.83 $^5D_2$: 1887.81 $^5D_3$: 1886.48 $^3D_1$: 1880.57 $^3D_2$: 1876.37 $^3D_3$: 1874.88
$11s$	$^5S_2$: 1728.54
$9f$	^5F: 1724.97
$10d$	$^5D_0$: — $^5D_3$: 1474.74 $^5D_2$: 1474.43 $^5D_1$: 1474.13 $^5D_4$: 1471.43
$10f$	^5F: 1362.24
$11d$	$^5D_0$: — $^5D_1$, $^5D_2$: 1186.7 $^5D_3$: 1184.52 $^5D_4$: 1184.04
$11f$	^5F: 1102.81

(^4S) limit, and their possible combinations with other terms built on the same limit lie at too long wave-lengths to be photographed. The combinations that are observed are all relatively weak, and although some of the unclassified lines are probably due to other terms of this configuration, it is not possible to identify them at present.

Two lines are observed having wave numbers agreeing with the differences of certain $4p^4$ terms; namely, $^1D_2-{}^1S_0$ and $^3P_1-{}^1S_0$. The former of these fits equally well as a $(^4S)5p\ {}^3P_2-(^4S)6d\ {}^5D_3$ intercombination, several other lines of which are also found, and this seems to be the more reasonable assignment. The latter, however, has no other place in the present term scheme except as this transition.

Table II contains all the known Se I terms with their numerical values referred to the ^4S state of the ion as zero. Those terms which are known to perturb each other are listed under their predominating configurations and with a common number in the parentheses to show the sharing configuration of each.

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The Paschen-Back Effect. II. *JJ*-Coupling (approx.)

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The Paschen-Back effect of four pairs of *mercury* lines, λλ5789–90, 3662–63, 3131–32 and 2967–68, have been measured. The results have been found to be in good agreement with Houston's theory, both as to position and intensities of components. *The red shift* of the central component of λ5790 was studied in greater detail at several field strengths and was found to be practically proportional to the square of the field strengths. *The Zeeman effect* of several other mercury lines was also measured, and the *g*-values calculated from them were slightly different from the normal *g*-values, but are in general accord with the values calculated from perturbation theory.

IN a previous communication,[1] the incomplete Paschen-Back effect of the Zn and Cd $^3P^3D$ multiplet was discussed. The agreement between Darwin's[2] calculations and experiment were very satisfactory. In Darwin's work, the effect of electrostatic interaction between the two electrons was neglected, so that the results could be expected to be satisfactory only for *LS*-coupling. The sd^3D and sd^1D terms of both Zn and Cd are sufficiently separated so that this approximation was valid. But in the case of Hg, the $6s4d^3D_1$ and $^1D_2$ are only 3 cm^{-1} apart, and in even moderately strong magnetic fields perturbing effects become quite large. Four groups of lines involving these two levels and the $6s6p^3P$ and ^1P levels, namely λλ5789–90, 3662–3, 3131–32, and 2967–68, were studied, with a view to comparing the experimental results with the theory of singlets and triplets developed by Houston.[3]

Houston has calculated the matrix elements of the interaction of two electrons (one an *s*-electorn) with an external magnetic field and has completed the calculations for weak fields, i.e., to first order terms. In our work we found that this method would not be sufficiently accurate even for our weakest fields, so that it was necessary to use the complete secular determinant of Houston and not to neglect the second and third order terms.

If $\psi=a_1\varphi_1+a_2\varphi_2+a_3\varphi_3+a_4\varphi_4$ be the zero-order approximation of the wave function where

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[1] Green and Gray, Phys. Rev. **45**, 273 (1934).

[2] Darwin, Proc. Roy. Soc. **A115**, 1 (1927).

[3] Houston, Phys. Rev. **33**, 297 (1929).