Arc Spectra of Gallium, Indium, and Thallium

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The arc spectra of gallium, indium, and thallium have been systematically investigated photographically in the octave 6500 to 13000 Angstroms. The spectra were excited in direct-current arcs and recorded on infrared sensitive photographic emulsions with a concave diffraction grating 22 feet in radius. In the designated spectral range, 37 new lines were photographed in Ga I, 35 lines in In I, and 25 lines in Tl I. All the observed lines are explained as combinations of doublet terms arising from the axial and orbital momenta of a single-valence electron. The new data led to a revision of Ga I terms, and extension from $n=9$ to 12 for $ns\,^2S$, from $n=7$ to 11 for $nd\,^2D$, and to the discovery of $nf\,^2F^\circ$ terms from $n=4$ to 7. Besides confirming many terms already known for In I and Tl I, two new $nf\,^2F^\circ$ terms were found for each of these spectra.

1. Introduction

This research was inspired by the compilation of "Atomic energy levels as derived from the analyses of optical spectra" [1].[1] While compiling the data on gallium spectra, C. E. Moore noted that the first spectrum of gallium (Ga I) was very incompletely investigated. In particular, no Ga I lines had been observed with wavelengths greater than 6414 A in the red, although two infrared lines (11904 and 12096 A) were predicted in 1914 from spectral-series formulas [2]. These predicted infrared lines have now been recorded photographically, and, in addition, 37 new Ga I lines have been discovered. These observations have led to revision and extension of the known atomic-energy levels as derived from the analysis of the Ga I spectrum.

Inspection of the published papers on In I and Tl I (analogues of Ga I) indicated that these spectra also had not been adequately investigated photographically in the region of longer waves. In 1938 Paschen [3] photographed the arc spectrum of indium to 9170 A, but the arc spectrum of thallium had never been photographed beyond 6900 A, although Paschen [4] in 1909–10 observed Tl lines from 8376.5 to 71170 A with a bolometer. Excepting Paschen's work on indium, the arc spectra of gallium, indium, and thallium have not been investigated photographically for 30 years, during which period infrared-sensitive emulsions permitting observations to 13000 A have become available. Observations on these spectra in the octave 6500 to 13000 A are reported in the present paper; in each case they led to the discovery of new spectral lines and terms so that the atomic-energy levels of Ga I, In I, and Tl I are now essentially complete.

2. Experimental Details

A conventional direct-current arc between copper electrodes was used for most of these experiments, but it was found necessary to employ also an arc at reduced pressure. The arc was operated with an applied potential of 220 v, and the arc current was rheostat regulated at 8 to 10 amp. The anode consisted of a cupped copper rod, ½ in. in diameter, and the cathode was a copper rod ¼ in. in diameter. To observe the spectrum of gallium, indium, or thallium the anodic cup was filled with a sample to be investigated. Liquid gallium was transferred from a vial to the cup with a platinum spoon, whereas pellets of indium or thallium were placed in the cup with tweezers. The arc in air was struck by drawing a graphite rod between the electrodes.

Because the emulsions available for infrared photography are rather insensitive compared with their response to violet light, success in recording spectra beyond 9000 A requires a bright source, ample sample, and long exposure, in addition to an efficient spectrograph. For example, to record the Tl I line at 13013 A required about 20 g of sample in a 10-amp arc exposed for 5 hours, whereas the iron comparison spectrum was recorded in the third order of the same grating in 1 second! Unfortunately, these source conditions produce spectral line images that are more or less hazy and asymmetrical, especially for red and infrared lines of Ga I, In I, and Tl I. That this is due to collision broadening rather than Doppler effect is shown by the fact that it is just as marked for Tl I as for Ga I, although Tl atoms are three times as massive as Ga atoms. Furthermore, analysis shows that the lines in question invariably involve highly excited states of type-*d* or type-*f* electrons; the transitions from type-*p* to type-*s* electrons always yield sharper lines.

Attempts to sharpen the newly observed lines by exciting them in an arc at reduced pressure were not wholly successful because sharpness and intensity are mutually exclusive in most light sources. Experiments were made with an enclosed arc [5] attached to a pump and pressure gage. When the residual air in the chamber was reduced to a few millimeters (Hg) the lines of Ga I, In I, and Tl I were sharp but faint, and mostly obscured by a strong background of N, O, and NO spectra. The sought lines are somewhat stronger when the pressure of residual air is 7 to 10 cm (Hg), but even then this source is too weak to photograph its lines beyond 9000 A with reasonable exposure time. This source, providing a compromise between intensity and sharpness of spectral lines, could be used in this investigation only in the range 6400 to 8900 A, for which region photographic emul-

[1] Figures in brackets indicate the literature references at the end of this paper.

sions are a hundredfold more sensitive than those used for longer waves. Without doubt, sharper lines could be obtained from discharges at very low pressure in a Paschen hollow cathode, but the present observations were restricted to the classical direct-current arc at atmospheric pressure or partial pressure.

Spectrograms were made with the stigmatic concave grating previously described [6], except that both the grating and mirror were aluminized some years ago. In its first-order spectrum this spectrograph has a reciprocal dispersion of 10 A/mm, and it is now used almost exclusively to photograph infrared spectra on 2- by 10-in. plates embracing wavelength ranges of 2500 A. The range from 10500 to 13000 A was photographed with Eastman I–Z plates, the range from 8500 to 11000 A with Eastman I–Q plates, and the range from 6400 to 8900 A with Eastman I–N plates. The I–Z and I–Q plates were hypersensitized by bathing for 2 minutes in 2- to 7-percent solutions of ammonia in water; they were then dried rapidly before loading in the spectrographic plate holder.

A dark-red-glass filter placed in front of the spectrograph slit absorbed overlapping spectral orders when the first-order spectrum was being photographed. Short portions of the slit were exposed to the iron arc to provide standards for wavelength measurement. For the spectral ranges covered by I–Q and I–Z plates, iron standards were taken from the second-, third-, or fourth-order spectra, but for the range observed with I–N plates the iron comparison spectrum was recorded in the same first order as the other spectra, a deep-yellow-glass filter being employed to absorb the overlapping spectral orders.

3. Results

The wavelengths belonging to lines observed in the arc spectra of gallium, indium, and thallium were calculated from linear measurements of the positions of these lines relative to standard lines in the iron spectrum, and then converted to first-order values if the iron standards appeared in higher spectral orders. Because most of these lines were naturally hazy (H) and shaded to longer (l) waves, it was usually impossible to specify the wavelength closer than ± 0.1 A, and small corrections due to slight departures from standard-air density were therefore neglected.

Relative intensities of the observed lines were estimated from the spectrograms and adjusted somewhat to correct for obviously excessive estimates when lines happened to be on or near the peak of sensitivity of a particular photographic emulsion. These estimates have physical meaning for proximate lines but may be misleading when comparing the intensities of widely separated lines. An example of the latter is discussed under thallium.

The results of this investigation are presented in two tables for each spectrum, the first gives the experimental data on wavelength, relative intensities and line character, and spectral-term combination, whereas the second table contains a complete list of the atomic-energy levels derived from the analyses of the optical spectra. In general, the Ga I, In I, and Tl I spectra are structurally similar, each line represents a transition of a single electron, which, by virtue of its axial and orbital momenta, gives the atomic-energy levels grouped to form doublet spectral terms. The only exception is a ^{4}P term observed in each of these spectra.

3.1. Gallium

The early history of gallium spectra is given in Kayser's Handbuch der Spectroscopie [7]. Briefly, 14 lines (2450 to 6414 A) reported by Exner and Haschek [8] in 1911 were arranged in three spectral series by Paschen and Meissner [2] in 1914. Uhler and Tanch [9] published for 23 arc lines of Ga wavelengths ranging from 2171.9 to 4172.048 A; Sawyer and Lang [10] added five lines (2607.47 to 2691.29 A), which fix a ^{4}P term, and this is all that was known about the Ga I spectrum to the present time. The present investigation more than doubles the total number of lines previously ascribed to Ga I, and because the final list has rejected some lines and substituted others it is given complete in table 1. This list of Ga I lines gives the best agreement with values calculated from established atomic energy levels displayed in table 2. We are indebted to C. E. Moore for selecting and adjusting these values of wavelengths and atomic-energy levels.

Besides revising some earlier term values, the present observations of Ga I lines have extended the series $5p\ ^2\mathrm{P}^\circ - ns\ ^2S$ from n=9 to 12, the series $5p\ ^2\mathrm{P}^\circ - nd\ ^2\mathrm{D}$ from $n=7$ to 11, and revealed the series $4d\ ^2\mathrm{D} - nf\ ^2\mathrm{F}^\circ$ from $n=4$ to 7, inclusive. The limit, 48380 cm^{-1}, corresponds to an ionization potential of 5.997 ev, the energy required to remove a valence electron from a neutral gallium atom.

3.2. Indium

The arc spectrum of indium was first investigated systematically by Kayser and Runge [13], who in 1893 measured the wavelengths (2180 to 4511 A) of 34 lines and arranged them in two subordinate spectral series. About 22 years later Paschen and Meissner [2] observed nine indium lines (4479 to 6900 A) and placed them in a principal series of doublets. In 1922 Uhler and Tanch [9] published wavelengths (2171 to 4511 A) for 34 indium lines, almost, but not quite, identical with the earlier list by Kayser and Runge [13]. An important contribution was made in 1938 by Paschen [3], who measured the In I spectrum emitted by Geissler tubes and by furnaces, and published wavelengths (2179.90 to 9170.2 A) and term combinations for 107 lines, 27 of which lie in the far red and near infrared. Unfortunately, Paschen neglected to give any intensities to these new lines, 21 of which are quoted by Kayser and Ritschl [14] in their table of principal lines, although they are mostly very weak compared with other In I lines. We have tried to supply estimates of the relative intensities of these In I lines, but a few were too weak and hazy to measure on the spectrograms.

TABLE 1. *The first spectrum of gallium,* Ga I

[h=hazy; H=very hazy; l=shaded to longer waves]

Reference	Wave length	Intensity and character	Wave number Observed	Wave number Calculated	Term combination
	A		*cm*$^{-1}$	*cm*$^{-1}$	
This work	12109. 93	200	8255. 43	5. 48	$5s\,^2S_{0\frac{1}{2}}-5p\,^2P^{\circ}_{0\frac{1}{2}}$
Do	11949. 24	400	8366. 45	6. 45	$5s\,^2S_{0\frac{1}{2}}-5p\,^2P^{\circ}_{1\frac{1}{2}}$
Do	11103. 90	20	9003. 38	3. 41	$5p\,^2P^{\circ}_{1\frac{1}{2}}-7s\,^2S_{0\frac{1}{2}}$
Do	10968. 64	10	9114. 41	4. 38	$5p\,^2P^{\circ}_{0\frac{1}{2}}-7s\,^2S_{0\frac{1}{2}}$
Do	10905. 96	100*Hl*	9166. 79	6. 79	$4d\,^2D_{2\frac{1}{2}}-4f\,^2F^{\circ}_{3\frac{1}{2}}$
Do	10898. 53	60*Hl*	9173. 05	3. 04	$4d\,^2D_{1\frac{1}{2}}-4f\,^2F^{\circ}_{2\frac{1}{2}}$
Do	9593. 98	20*h*	10420. 35	0. 35	$5p\,^2P^{\circ}_{1\frac{1}{2}}-6d\,^2D_{1\frac{1}{2}}$
Do	9589. 18	300*h*	10425. 56	5. 56	$5p\,^2P^{\circ}_{1\frac{1}{2}}-6d\,^2D_{2\frac{1}{2}}$
Do	9492. 88	200*h*	10531. 32	1. 32	$5p\,^2P^{\circ}_{0\frac{1}{2}}-6d\,^2D_{1\frac{1}{2}}$
Do	8944. 6	30*h*	11176. 9	6. 9	$5p\,^2P^{\circ}_{1\frac{1}{2}}-8s\,^2S_{0\frac{1}{2}}$
Do	8856. 6	20*h*	11287. 9	7. 8	$5p\,^2P^{\circ}_{0\frac{1}{2}}-8s\,^2S_{0\frac{1}{2}}$
Do	8813. 7	30*Hl*	11342. 8	2. 8	$4d\,^2D_{2\frac{1}{2}}-5f\,^2F^{\circ}_{3\frac{1}{2}}$
Do	8808. 9	20*Hl*	11349. 0	9. 0	$4d\,^2D_{1\frac{1}{2}}-5f\,^2F^{\circ}_{2\frac{1}{2}}$
Do	8420. 3	10*Hl*	11872. 8	2. 9	$4d\,^2D_{2\frac{1}{2}}-6f\,^2F^{\circ}_{3\frac{1}{2}}$
Do	8415. 8	7*Hl*	11879. 1	9. 1	$4d\,^2D_{1\frac{1}{2}}-6f\,^2F^{\circ}_{2\frac{1}{2}}$
Do	8389. 2	10*h*	11916. 8	7. 0	$5p\,^2P^{\circ}_{1\frac{1}{2}}-7d\,^2D_{1\frac{1}{2}}$
Do	8386. 2	200*h*	11921. 1	1. 1	$5p\,^2P^{\circ}_{1\frac{1}{2}}-7d\,^2D_{2\frac{1}{2}}$
Do	8311. 5	100*h*	12028. 1	7. 9	$5p\,^2P^{\circ}_{0\frac{1}{2}}-7d\,^2D_{1\frac{1}{2}}$
Do	8171. 6	5*Hl*	12234. 1	4. 1	$4d\,^2D_{2\frac{1}{2}}-7f\,^2F^{\circ}_{3\frac{1}{2}}$
Do	8167. 5	3*Hl*	12240. 3	0. 3	$4d\,^2D_{1\frac{1}{2}}-7f\,^2F^{\circ}_{2\frac{1}{2}}$
Do	8074. 25	20*h*	12381. 65	1. 63	$5p\,^2P^{\circ}_{1\frac{1}{2}}-9s\,^2S_{0\frac{1}{2}}$
Do	8002. 55	15*h*	12492. 58	2. 60	$5p\,^2P^{\circ}_{0\frac{1}{2}}-9s\,^2S_{0\frac{1}{2}}$
Do	7801. 6	4*h*	12814. 3	4. 2	$5p\,^2P^{\circ}_{1\frac{1}{2}}-8d\,^2D_{1\frac{1}{2}}$
Do	7800. 01	100*h*	12816. 97	6. 97	$5p\,^2P^{\circ}_{1\frac{1}{2}}-8d\,^2D_{2\frac{1}{2}}$
Do	7734. 77	50*h*	12925. 08	5. 1	$5p\,^2P^{\circ}_{0\frac{1}{2}}-8d\,^2D_{1\frac{1}{2}}$
Do	7620. 5	10*hl*	13118. 9	8. 9	$5p\,^2P^{\circ}_{1\frac{1}{2}}-10s\,^2S_{0\frac{1}{2}}$
Do	7556. 6	6*h*	13229. 8	9. 8	$5p\,^2P^{\circ}_{0\frac{1}{2}}-10s\,^2S_{0\frac{1}{2}}$
Do	7464. 0	30*Hl*	13393. 9	3. 9	$5p\,^2P^{\circ}_{1\frac{1}{2}}-9d\,^2D_{2\frac{1}{2}}$
Do	7403. 0	20*Hl*	13504. 3	4. 2	$5p\,^2P^{\circ}_{0\frac{1}{2}}-9d\,^2D_{1\frac{1}{2}}$
Do	7349. 3	5*hl*	13603. 0	3. 2	$5p\,^2P^{\circ}_{1\frac{1}{2}}-11s\,^2S_{0\frac{1}{2}}$
Do	7289. 6	3*hl*	13714. 4	4. 1	$5p\,^2P^{\circ}_{0\frac{1}{2}}-11s\,^2S_{0\frac{1}{2}}$
Do	7251. 4	10*Hl*	13786. 6	6. 6	$5p\,^2P^{\circ}_{1\frac{1}{2}}-10d\,^2D_{2\frac{1}{2}}$
Do	7193. 6	5*Hl*	13897. 4	7. 5	$5p\,^2P^{\circ}_{0\frac{1}{2}}-10d\,^2D_{1\frac{1}{2}}$
Do	7172. 9	2*h*	13937. 5	7. 5	$5p\,^2P^{\circ}_{1\frac{1}{2}}-12s\,^2S_{0\frac{1}{2}}$
Do	7116. 3	1*h*	14048. 4	8. 5	$5p\,^2P^{\circ}_{0\frac{1}{2}}-12s\,^2S_{0\frac{1}{2}}$

Because the sources employed by Paschen emitted sharper lines, we have quoted his wavelength and wave number values in table 3 in addition to the measured wavelengths, estimated intensities, vacuum wave numbers, and term combinations for 40 In I lines ranging in wavelength from 6847.44 to 12912.6 A. The remainder of the In I spectrum is fully presented (excepting intensities) in Paschen's paper [3]. An extension of the ^2D and ^2S series has been reported by Garton [15], but no details of measurement are available at present.

The complete list of atomic energy levels of In I is found in table 4, where Paschen's term values appear (relative to $5s^2\,5p\,^2P^{\circ}_{0\frac{1}{2}}=0.00$), and two new terms ($5f\,^2F^{\circ}$ and $6f\,^2F^{\circ}$) have been interpolated from our infrared observations.

From the limit, 46669.9 cm^{-1}, an ionization potential of 5.785 ev is derived for indium atoms.

3.3. Thallium

The last complete compilation of literature on the spectra of thallium was published 40 years ago by Kayser [16]. As in the case of indium, the first careful investigation of the arc spectrum of thallium was made in 1893 by Kayser and Runge [13], who measured the wavelengths (2129 to 5528 A) of 49 lines and assigned nearly all of them to a principal and to two subordinate series. Four additional visible lines were photographed in 1910 by Eder and Valenta [17], but to this day nobody has reported photographing the Tl I spectrum beyond 6714 A in the red. The infrared emission spectrum of thallium was first explored by Paschen [4], who employed a bolometer and galvanometer to detect about three dozen lines with wavelengths ranging from 8376.5 to 71170 A. The most prominent pair of these infrared lines (11513 and 13014 A) was accounted for by the established series terms, and most of the remainder were interpreted as in agreement with values calculated from the Ritz combination principle applied to known Tl I terms. Some

TABLE 1. *The first spectrum of gallium*, Ga I—Continued

[h=hazy: H=very hazy: l=shaded to longer waves]

Reference	Wave length	Intensity and character	Wave number		Term combination
			Observed	Calculated	
	A		cm^{-1}	cm^{-1}	
This work	7106.82	$5hl$	14067.12	7.07	$5p\,^2P^{\circ}_{1\frac{1}{2}}-11d\,^2D_{2\frac{1}{2}}$
Do	7051.24	$3hl$	14178.00	8.04	$5p\,^2P^{\circ}_{0\frac{1}{2}}-11d\,^2D_{1\frac{1}{2}}$
Do	6413.47	1000	15587.88	7.88	$5s\,^2S_{0\frac{1}{2}}-6p\,^2P^{\circ}_{0\frac{1}{2}}$
Do	6396.58	2000	15629.04	9.04	$5s\,^2S_{0\frac{1}{2}}-6p\,^2P^{\circ}_{1\frac{1}{2}}$
[11]	5359.8	--------	18652.2	2.2	$5s\,^2S_{0\frac{1}{2}}-7p\,^2P^{\circ}_{0\frac{1}{2}}$
[11]	5353.81	2	18673.1	3.1	$5s\,^2S_{0\frac{1}{2}}-7p\,^2P^{\circ}_{1\frac{1}{2}}$
[9]	4172.048	10	23962.31	2.34	$4p\,^2P^{\circ}_{1\frac{1}{2}}-5s\,^2S_{0\frac{1}{2}}$
[9]	4032.975	10	24788.61	8.58	$4p\,^2P^{\circ}_{0\frac{1}{2}}-5s\,^2S_{0\frac{1}{2}}$
[9]	2944.175	6	33955.47	5.43	$4p\,^2P^{\circ}_{1\frac{1}{2}}-4d\,^2D_{1\frac{1}{2}}$
[9]	2943.639	6	33961.66	1.68	$4p\,^2P^{\circ}_{1\frac{1}{2}}-4d\,^2D_{2\frac{1}{2}}$
[9]	2874.240	6	34781.63	1.67	$4p\,^2P^{\circ}_{0\frac{1}{2}}-4d\,^2D_{1\frac{1}{2}}$
[9]	2719.664	3	36758.39	8.38	$4p\,^2P^{\circ}_{1\frac{1}{2}}-6s\,^2S_{0\frac{1}{2}}$
[10]	2691.29	(8)	37146	6	$4p\,^2P^{\circ}_{1\frac{1}{2}}-4p^2\,^4P_{0\frac{1}{2}}$
[10]	2665.05	(10)	37511	2	$4p\,^2P^{\circ}_{1\frac{1}{2}}-4p^2\,^4P_{1\frac{1}{2}}$
[11]	2659.873	3	37584.62	4.62	$4p\,^2P^{\circ}_{0\frac{1}{2}}-6s\,^2S_{0\frac{1}{2}}$
[10]	2632.66	(10)	37972	2	$4p\,^2P^{\circ}_{0\frac{1}{2}}-4p^2\,^4P_{0\frac{1}{2}}$
[10]	2624.82	(8)	38087	7	$4p\,^2P^{\circ}_{1\frac{1}{2}}-4p^2\,^4P_{2\frac{1}{2}}$
[10]	2607.47	(5)	38339	8	$4p\,^2P^{\circ}_{0\frac{1}{2}}-4p^2\,^4P_{1\frac{1}{2}}$
[9]	2500.714	3	39976.53	6.48	$4p\,^2P^{\circ}_{1\frac{1}{2}}-5d\,^2D_{1\frac{1}{2}}$
[9]	2500.187	7	39984.96	4.96	$4p\,^2P^{\circ}_{1\frac{1}{2}}-5d\,^2D_{2\frac{1}{2}}$
[9]	2450.078	6	40802.67	2.72	$4p\,^2P^{\circ}_{0\frac{1}{2}}-5d\,^2D_{1\frac{1}{2}}$
[12]	2418.69	(4)	41332.1	2.2	$4p\,^2P^{\circ}_{1\frac{1}{2}}-7s\,^2S_{0\frac{1}{2}}$
[12]	2371.29	(3)	42158.25	8.44	$4p\,^2P^{\circ}_{0\frac{1}{2}}-7s\,^2S_{0\frac{1}{2}}$
[9]	2338.596	1	42747.57	9.14	$4p\,^2P^{\circ}_{1\frac{1}{2}}-6d\,^2D_{1\frac{1}{2}}$
[12]	2338.24	(3)	42754.08	4.35	$4p\,^2P^{\circ}_{1\frac{1}{2}}-6d\,^2D_{2\frac{1}{2}}$
[9]	2297.869	1	43505.15	5.6	$4p\,^2P^{\circ}_{1\frac{1}{2}}-8s\,^2S_{0\frac{1}{2}}$
[12]	2294.19	(2)	43574.91	5.38	$4p\,^2P^{\circ}_{0\frac{1}{2}}-6d\,^2D_{1\frac{1}{2}}$
[9]	2259.227	1	44249.19	9.87	$4p\,^2P^{\circ}_{1\frac{1}{2}}-7d\,^2D_{2\frac{1}{2}}$
[9]	2255.034	1	44331.46	1.8	$4p\,^2P^{\circ}_{0\frac{1}{2}}-8s\,^2S_{0\frac{1}{2}}$
[9]	2218.039	1	45070.80	2.0	$4p\,^2P^{\circ}_{0\frac{1}{2}}-7d\,^2D_{1\frac{1}{2}}$

of Paschen's infrared Tl lines remain unexplained, although all theoretically possible Tl I terms of any importance are now known. Because some of the proposed combinations are discordant and are forbidden by rigid quantum rules, they must be regarded with suspicion. Additional doubt is cast upon some of Paschen's lines by the fact that in the range observed both bolometrically and photographically there are serious disagreements, Paschen reported some lines that we could not photograph and we photographed some that he did not detect. These differences are shown in table 5, which presents the reported lines in the range of wavelengths, 6549.84 to 13013.2 A, 22 lines with greater wavelengths, according to Paschen, being omitted.

The Tl I line at 13013.2 A is the greatest wavelength that has been recorded by direct photography of metallic arc spectra, and it could be recorded only because it is intrinsically intense. By comparing the photographic density of this line with that of its companion at 11512.8 A, one can conclude that the sensitivity of the I–Z emulsion for 13000 A is of the order of one one-thousandth its maximum sensitivity near 11000 A. It would be a great boon to spectroscopy if the proper dyes could be synthesized and incorporated in emulsions to produce photographic sensitivity at still greater wavelengths.

The Tl I data available in 1922 were collected by Fowler [11] in his report on "Series in line spectra," and the relative values of his atomic energy level' referred to the ground state ($6s^2\,6p\,^2P^{\circ}_{0\frac{1}{2}}=0.0$) are presented below in table 6, together with the appropriate quantum notation, and with the inclusion of two new terms ($7f\,^2F^{\circ}$ and $8f\,^2F^{\circ}$) derived from the infrared observations.

Longer series have been traced in the Tl I spectrum than in any other spectrum excepting hydrogen and alkali metals. Thus in Tl I the principal quantum number, or shell, for s electrons has been traced to 20, for p electrons to 16, for d electrons to 23, and for f electrons to 8. The extrapolated limit of these series is 49264.2 cm^{-1} from the ground state, and the corresponding ionization potential of Tl is 6.1063 ev.

TABLE 2. *Atomic energy levels of* Ga I

Electron configuration	Term symbol	J	Level value	Interval
			cm^{-1}	
$4s^2(^1S)\ 4p$	$4p\ ^2P^0$	$0\frac{1}{2}$ $1\frac{1}{2}$	*0. 00* *826. 24*	826. 24
$4s^2(^1S)\ 5s$	$5s\ ^2S$	$0\frac{1}{2}$	24788. 58	
$4s^2(^1S)\ 5p$	$5p\ ^2P^0$	$0\frac{1}{2}$ $1\frac{1}{2}$	*33044. 06* *33155. 03*	110. 97
$4s^2(^1S)\ 4d$	$4d\ ^2D$	$1\frac{1}{2}$ $2\frac{1}{2}$	34781. 67 34787. 92	6. 25
$4s^2(^1S)\ 6s$	$6s\ ^2S$	$0\frac{1}{2}$	37584. 62	
$4s\ 4p^2$	$4p^2\ ^4P$	$0\frac{1}{2}$ $1\frac{1}{2}$ $2\frac{1}{2}$	37972 38338 38913	366 575
$4s^2(^1S)\ 6p$	$6p\ ^2P^0$	$0\frac{1}{2}$ $1\frac{1}{2}$	*40376. 46* *40417. 62*	41. 16
$4s^2(^1S)\ 5d$	$5d\ ^2D$	$1\frac{1}{2}$ $2\frac{1}{2}$	40802. 72 40811. 20	8. 48
$4s^2(^1S)\ 7s$	$7s\ ^2S$	$0\frac{1}{2}$	42158. 44	
$4s^2(^1S)\ 7p$	$7p\ ^2P^0$	$0\frac{1}{2}$ $1\frac{1}{2}$	*43440. 8* *43461. 7*	20. 9
$4s^2(^1S)\ 6d$	$6d\ ^2D$	$1\frac{1}{2}$ $2\frac{1}{2}$	43575. 38 43580. 59	5. 21
$4s^2(^1S)\ 4f$	$4f\ ^2F^0$	$2\frac{1}{2}, 3\frac{1}{2}$	*43954. 71*	
$4s^2(^1S)\ 8s$	$8s\ ^2S$	$0\frac{1}{2}$	44331. 9	
$4s^2(^1S)\ 7d$	$7d\ ^2D$	$1\frac{1}{2}$ $2\frac{1}{2}$	45072. 0 45076. 1	4. 1
$4s^2(^1S)\ 9s$	$9s\ ^2S$	$0\frac{1}{2}$	45536. 66	
$4s^2(^1S)\ 8d$	$8d\ ^2D$	$1\frac{1}{2}$ $2\frac{1}{2}$	45969. 2 45972. 0	2. 8
$4s^2(^1S)\ 5f$	$5f\ ^2F^0$	$2\frac{1}{2}, 3\frac{1}{2}$	*46130. 7*	
$4s^2(^1S)\ 10s$	$10s\ ^2S$	$0\frac{1}{2}$	46273. 9	
$4s^2(^1S)\ 9d$	$9d\ ^2D$	$1\frac{1}{2}$ $2\frac{1}{2}$	46548. 3 46548. 9	0. 6
$4s^2(^1S)\ 6f$	$6f\ ^2F^0$	$2\frac{1}{2}, 3\frac{1}{2}$	*46660. 8*	
$4s^2(^1S)\ 11s$	$11s\ ^2S$	$0\frac{1}{2}$	46758. 2	
$4s^2(^1S)\ 10d$	$10d\ ^2D$	$1\frac{1}{2}, 2\frac{1}{2}$	46941. 6	
$4s^2(^1S)\ 7f$	$7f\ ^2F^0$	$2\frac{1}{2}, 3\frac{1}{2}$	*47022. 0*	
$4s^2(^1S)\ 12s$	$12s\ ^2S$	$0\frac{1}{2}$	47092. 52	
$4s^2(^1S)\ 11d$	$11d\ ^2D$	$1\frac{1}{2}, 2\frac{1}{2}$	47222. 10	
------------	----------	----------	----------	
Ga II $(^1S_0)$	*Limit*		**48380**	
$4s\ 4p^2$	$4p^2\ ^2S$	$0\frac{1}{2}$	62100	
$4s\ 4p^2$	$4p^2\ ^2P$	$0\frac{1}{2}$ $1\frac{1}{2}$	65796 66422	626

TABLE 3. *First spectrum of indium,* In I

[*h*=hazy, *H*=very hazy, *l*=shaded to longer waves]

Wave length	Intensity and character	Wave length Paschen [14]	Wave number		Term combination
			Observed	Calculated	
A		*A*	cm^{-1}	cm^{-1}	
12912. 6	10	--------	7442. 2	1. 92	$6s\ ^2S_{0\frac{1}{2}}-6p\ ^2P^{\circ}_{1\frac{1}{2}}$
11731. 5	20*h*	--------	8521. 7	1. 92	$6p\ ^2P^{\circ}_{1\frac{1}{2}}-8s\ ^2S_{0\frac{1}{2}}$
11334. 9	20*h*	--------	8819. 9	20. 10	$6p\ ^2P^{\circ}_{0\frac{1}{2}}-8s\ ^2S_{0\frac{1}{2}}$
10744. 5	100*Hl*	--------	9304. 54	4. 6	$5d\ ^2D_{2\frac{1}{2}}-5f\ ^2F^{\circ}_{3\frac{1}{2}}$
10717. 5	60*Hl*	--------	9327. 98	7. 9	$5d\ ^2D_{1\frac{1}{2}}-5f\ ^2F^{\circ}_{2\frac{1}{2}}$
10283. 9	5*H*	--------	9721. 27	1. 44	$6p\ ^2P^{\circ}_{1\frac{1}{2}}-7d\ ^2D_{1\frac{1}{2}}$
10257. 3	200*hl*	--------	9746. 48	6. 78	$6p\ ^2P^{\circ}_{1\frac{1}{2}}-7d\ ^2D_{2\frac{1}{2}}$
9977. 5	100*hl*	--------	10019. 8	9. 62	$6p\ ^2P^{\circ}_{0\frac{1}{2}}-7d\ ^2D_{1\frac{1}{2}}$
9428. 2	20*h*	--------	10603. 6	3. 76	$6p\ ^2P^{\circ}_{1\frac{1}{2}}-9s\ ^2S_{0\frac{1}{2}}$
9370. 4	60*Hl*	--------	10669. 0	9. 0	$5d\ ^2D_{2\frac{1}{2}}-6f\ ^2F^{\circ}_{3\frac{1}{2}}$
9350. 0	40*Hl*	--------	10692. 3	2. 3	$5d\ ^2D_{1\frac{1}{2}}-6f\ ^2F^{\circ}_{2\frac{1}{2}}$
9170. 2	10*h*	9170. 2	10901. 9	1. 94	$6p\ ^2P^{\circ}_{0\frac{1}{2}}-9s\ ^2S_{0\frac{1}{2}}$
8909. 6	4*h*	8909. 53	11220. 86	0. 84	$6p\ ^2P^{\circ}_{1\frac{1}{2}}-8d\ ^2D_{1\frac{1}{2}}$
8894. 7	40*hl*	8894. 48	11239. 85	9. 83	$6p\ ^2P^{\circ}_{1\frac{1}{2}}-8d\ ^2D_{2\frac{1}{2}}$
8700. 4	50*hl*	8700. 19	11490. 85	0. 84	$5d\ ^2D_{2\frac{1}{2}}-7f\ ^2F^{\circ}_{3\frac{1}{2}}$
8682. 7	20*hl*	8682. 64	11514. 08	4. 08	$5d\ ^2D_{1\frac{1}{2}}-7f\ ^2F^{\circ}_{2\frac{1}{2}}$
8679. 2	30*hl*	8678. 93	11519. 00	9. 02	$6p\ ^2P^{\circ}_{0\frac{1}{2}}-8d\ ^2D_{1\frac{1}{2}}$
8496. 8	15*h*	8496. 70	11766. 05	6. 04	$6p\ ^2P^{\circ}_{1\frac{1}{2}}-10s\ ^2S_{0\frac{1}{2}}$
8315. 0	15*Hl*	8314. 91	12023. 27	3. 28	$5d\ ^2D_{2\frac{1}{2}}-8f\ ^2F^{\circ}_{3\frac{1}{2}}$
8299. 1	10*Hl*	8298. 82	12046. 60	6. 59	$5d\ ^2D_{1\frac{1}{2}}-8f\ ^2F^{\circ}_{2\frac{1}{2}}$
8286. 7	10*h*	8286. 63	12064. 22	4. 22	$6p\ ^2P^{\circ}_{0\frac{1}{2}}-10s\ ^2S_{0\frac{1}{2}}$
8249. 1	2*h*	8248. 93	12119. 46	9. 47	$6p\ ^2P^{\circ}_{1\frac{1}{2}}-9d\ ^2D_{1\frac{1}{2}}$
8238. 8	30*Hl*	8238. 64	12134. 59	4. 58	$6p\ ^2P^{\circ}_{1\frac{1}{2}}-9d\ ^2D_{2\frac{1}{2}}$
8070. 3	3*H*	8070. 18	12387. 90	7. 89	$5d\ ^2D_{2\frac{1}{2}}-9f\ ^2F^{\circ}_{3\frac{1}{2}}$
8055. 0	2*H*	8054. 98	12411. 27	1. 27	$5d\ ^2D_{1\frac{1}{2}}-9f\ ^2F^{\circ}_{2\frac{1}{2}}$
8050. 9	20*Hl*	8050. 81	12417. 70	7. 65	$6p\ ^2P^{\circ}_{0\frac{1}{2}}-9d\ ^2D_{1\frac{1}{2}}$
8010. 0	7*h*	8009. 93	12481. 07	1. 07	$6p\ ^2P^{\circ}_{1\frac{1}{2}}-11s\ ^2S_{0\frac{1}{2}}$
--------	--------	7903. 92	12648. 47	8. 47	$5d\ ^2D_{2\frac{1}{2}}-10f\ ^2F^{\circ}_{3\frac{1}{2}}$
--------	--------	7889. 28	12671. 94	1. 92	$5d\ ^2D_{1\frac{1}{2}}-10f\ ^2F^{\circ}_{2\frac{1}{2}}$
7871. 8	2*H*	7871. 71	12700. 23	0. 27	$6p\ ^2P^{\circ}_{1\frac{1}{2}}-10d\ ^2D_{1\frac{1}{2}}$
7864. 5	10*Hl*	7864. 27	12712. 24	2. 23	$6p\ ^2P^{\circ}_{1\frac{1}{2}}-10d\ ^2D_{2\frac{1}{2}}$
7823. 0	5*h*	7823. 08	12779. 17	9. 25	$6p\ ^2P^{\circ}_{0\frac{1}{2}}-11s\ ^2S_{0\frac{1}{2}}$
--------	--------	7785. 33	12841. 14	1. 14	$5d\ ^2D_{2\frac{1}{2}}-11f\ ^2F^{\circ}_{3\frac{1}{2}}$
--------	--------	7771. 26	12864. 39	4. 38	$5d\ ^2D_{1\frac{1}{2}}-11f\ ^2F^{\circ}_{2\frac{1}{2}}$
--------	--------	7697. 6	12987. 5	7. 50	$5d\ ^2D_{2\frac{1}{2}}-12f\ ^2F^{\circ}_{3\frac{1}{2}}$
7691. 2	6*Hl*	7691. 04	12998. 57	8. 45	$6p\ ^2P^{\circ}_{0\frac{1}{2}}-10d\ ^2D_{1\frac{1}{2}}$
7628. 0	4*H*	7627. 83	13006. 28	6. 29	$6p\ ^2P^{\circ}_{1\frac{1}{2}}-11d\ ^2D_{2\frac{1}{2}}$
7464.	2*H*	7463. 48	13394. 89	4. 90	$6p\ ^2P^{\circ}_{0\frac{1}{2}}-11d\ ^2D_{1\frac{1}{2}}$
6900. 14	1000	6900. 13	14488. 49	8. 48	$6s\ ^2S_{0\frac{1}{2}}-7p\ ^2P^{\circ}_{0\frac{1}{2}}$
6847. 45	2000	6847. 44	14599. 97	9. 97	$6s\ ^2S_{0\frac{1}{2}}-7p\ ^2P^{\circ}_{1\frac{1}{2}}$

TABLE 4. *Atomic energy levels of* In I

Electron configuration	Term symbol	J	Level value	Interval
			cm^{-1}	
$5s^2(^1S)\ 5p$	$5p\ ^2P^\circ$	0½ 1½	*0.00* *2212.56*	2212.56
$5s^2(^1S)\ 6s$	$6s\ ^2S$	0½	24372.87	
$5s^2(^1S)\ 6p$	$6p\ ^2P^\circ$	0½ 1½	*31816.61* *32114.79*	298.18
$5s^2(^1S)\ 5d$	$5d\ ^2D$	1½ 2½	32892.12 32915.42	23.30
$5s\ 5p^2$	$5p^2\ ^4P$	0½ 1½ 2½	34977.66 36020.80 37451.90	1043.14 1431.10
$5s^2(^1S)\ 7s$	$7s\ ^2S$	0½	36301.69	
$5s^2(^1S)\ 7p$	$7p\ ^2P^\circ$	0½ 1½	*38861.35* *38972.84*	111.49
$5s^2(^1S)\ 6d$	$6d\ ^2D$	1½ 2½	39048.48 39098.37	49.89
$5s\ 5p^2$	$5p^2\ ^2D$	1½ 2½	39707.29 39707.96	0.67
$5s^2(^1S)\ 8s$	$8s\ ^2S$	0½	40636.71	
$5s^2(^1S)\ 8p$	$8p\ ^2P^\circ$	0½ 1½	*41827.10* *41881.44*	54.34
$5s^2(^1S)\ 7d$	$7d\ ^2D$	1½ 2½	41836.23 41861.57	25.34
$5s^2(^1S)\ 5f$	$5f\ ^2F^\circ$	2½, 3½	*42220.0*	
$5s^2(^1S)\ 9s$	$9s\ ^2S$	0½	42718.55	
$5s^2(^1S)\ 8d$	$8d\ ^2D$	1½ 2½	43335.63 43354.62	18.99
$5s^2(^1S)\ 9p$	$9p\ ^2P^\circ$	0½ 1½	*43369.09* *43399.53*	30.44
$5s^2(^1S)\ 6f$	$6f\ ^2F^\circ$	2½, 3½	*43584.4*	
$5s^2(^1S)10s$	$10s\ ^2S$	0½	43880.83	
$5s^2(^1S)\ 9d$	$9d\ ^2D$	1½ 2½	44234.26 44249.37	15.11
$5s^2(^1S)10p$	$10p\ ^2P^\circ$	0½ 1½	*44275.17* *44294.13*	18.96
$5s^2(^1S)\ 7f$	$7f\ ^2F^\circ$	2½ 3½	*44406.20* *44406.26*	0.06
$5s^2(^1S)11s$	$11s\ ^2S$	0½	44595.86	
$5s^2(^1S)10d$	$10d\ ^2D$	1½ 2½	44815.06 44827.02	11.96
$5s^2(^1S)11p$	$11p\ ^2P^\circ$	0½ 1½	[*44853.23*] *44865.79*	[12.56]
$5s^2(^1S)\ 8f$	$8f\ ^2F^\circ$	3½ 2½	*44938.70* *44938.71*	−0.01
$5s^2(^1S)12s$	$12s\ ^2S$	0½	45067.19	

TABLE 4. *Atomic energy levels of* In I—Continued

Electron configuration	Term symbol	J	Level value	Interval
			cm^{-1}	
$5s^2(^1S)11d$	11d ^2D	$1\frac{1}{2}$ $2\frac{1}{2}$	45211. 51 45221. 08	9. 57
$5s^2(^1S)$ $9f$	$9f$ $^2F°$	$3\frac{1}{2}$ $2\frac{1}{2}$	*45303. 31* *45303. 39*	−0. 08
$5s^2(^1S)13s$	$13s$ ^2S	$0\frac{1}{2}$	45394. 13	
$5s^2(^1S)12d$	$12d$ ^2D	$1\frac{1}{2}$ $2\frac{1}{2}$	45493. 98 45502. 04	8. 06
$5s^2(^1S)10f$	$10f$ $^2F°$	$3\frac{1}{2}$ $2\frac{1}{2}$	*45563. 89* *45564. 04*	−0. 15
$5s^2(^1S)14s$	$14s$ ^2S	$0\frac{1}{2}$	45630. 44	
$5s^2(^1S)13d$	$13d$ ^2D	$1\frac{1}{2}$ $2\frac{1}{2}$	45702. 08 45709. 02	6. 94
$5s^2(^1S)11f$	$11f$ $^2F°$	$2\frac{1}{2}$ $3\frac{1}{2}$	*45756. 50* *45756. 56*	0. 06
$5s^2(^1S)15s$	$15s$ ^2S	$0\frac{1}{2}$	45806. 88	
$5s^2(^1S)14d$	$14d$ ^2D	$1\frac{1}{2}$ $2\frac{1}{2}$	45859. 30 45865. 32	6. 02
$5s^2(^1S)12f$	$12f$ $^2F°$	$2\frac{1}{2}$ $3\frac{1}{2}$	---------- *45902. 92*	
$5s^2(^1S)15d$	$15d$ ^2D	$1\frac{1}{2}$, $2\frac{1}{2}$	45986. 69	
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In II ($^1S_0$)	*Limit*		**46669. 93**	
$5s$ $5p^2$	$5p^2$ ^2P	$0\frac{1}{2}$ $1\frac{1}{2}$	59650 60660	1010

TABLE 5. *First spectrum of thallium*, Tl I

[*h*=hazy, *H*=very hazy, *l*=shaded to longer waves]

Wavelength	Intensity and character	Wavelength Paschen [4]	Intensity Paschen [4]	Wave number Observed	Wave number Calculated	Term combination
A		*A*		cm^{-1}	cm^{-1}	
13013.2	2	13013.8	700	7682.4	2.1	$7s\ {}^2S_{0\frac{1}{2}} - 7p\ {}^2P^{\circ}_{0\frac{1}{2}}$
--------	------	12736.4	150	7849.4	51.8	$7p\ {}^2P^{\circ}_{0\frac{1}{2}} - 7d\ {}^2D_{1\frac{1}{2}}$
--------	------	12728.2	20	7854.4	----	----------------
--------	------	12491.8	15	8003.1	5.2	$7p\ {}^2P^{\circ}_{1\frac{1}{2}} - 9s\ {}^2S_{0\frac{1}{2}}$
--------	------	11690.7	10	8551.5	----	----------------
11592.9	5*hl*	11594.5	80	8623.6	3.6	$6d\ {}^2D_{2\frac{1}{2}} - 6f\ {}^2F^{\circ}_{3\frac{1}{2}}$
11512.82	1000	11513.22	1000	8683.59	3.2	$7s\ {}^2S_{0\frac{1}{2}} - 7p\ {}^2P^{\circ}_{1\frac{1}{2}}$
11483.7	4*hl*	11482.2	50	8705.6	5.5	$6d\ {}^2D_{1\frac{1}{2}} - 6f\ {}^2F^{\circ}_{2\frac{1}{2}}$
11101.61	5*h*	--------	----	9005.24	6.6	$7p\ {}^2P^{\circ}_{0\frac{1}{2}} - 9s\ {}^2S_{0\frac{1}{2}}$
--------	------	10496.4	80	9524.5	11.8	$7p\ {}^2P^{\circ}_{1\frac{1}{2}} - 8d\ {}^2D_{1\frac{1}{2}}$
10488.80	40*hl*	10492.5	50	9531.37	1.9	$7p\ {}^2P^{\circ}_{1\frac{1}{2}} - 8d\ {}^2D_{2\frac{1}{2}}$
--------	------	10292.3	60	9713.3	22.4	$7s\ {}^2S_{0\frac{1}{2}} - 6d\ {}^2D_{2\frac{1}{2}}$
10011.9	30*hl*	--------	----	9985.4	5.4	$6d\ {}^2D_{2\frac{1}{2}} - 7f\ {}^2F^{\circ}_{3\frac{1}{2}}$
9937.4	2*h*	--------	----	10060.2	59.0	$7p\ {}^2P^{\circ}_{1\frac{1}{2}} - 6p^2\ {}^4P_{0\frac{1}{2}}$
9930.4	20*hl*	--------	----	10067.3	7.3	$6d\ {}^2D_{1\frac{1}{2}} - 7f\ {}^2F^{\circ}_{2\frac{1}{2}}$
9863.4	10*h*	--------	----	10135.7	6.0	$7p\ {}^2P^{\circ}_{1\frac{1}{2}} - 10s\ {}^2S_{0\frac{1}{2}}$
9509.4	40*hl*	9512.8	30	10513.0	3.1	$7p\ {}^2P^{\circ}_{0\frac{1}{2}} - 8d\ {}^2D_{1\frac{1}{2}}$
9252.6	2*H*	--------	----	10804.8	4.7	$6d\ {}^2D_{2\frac{1}{2}} - 8f\ {}^2F^{\circ}_{3\frac{1}{2}}$
9183.1	2*H*	--------	----	10886.6	6.6	$6d\ {}^2D_{1\frac{1}{2}} - 8f\ {}^2F^{\circ}_{2\frac{1}{2}}$
--------	------	9171.1	20	10900.8	----	----------------
9130.5	20*hl*	--------	----	10949.3	9.5	$7p\ {}^2P^{\circ}_{1\frac{1}{2}} - 9d\ {}^2D_{2\frac{1}{2}}$
9038.4	3	--------	----	11060.9	0.2	$7p\ {}^2P^{\circ}_{0\frac{1}{2}} - 6p^2\ {}^4P_{0\frac{1}{2}}$
8976.75	5*h*	--------	----	11136.8	7.2	$7p\ {}^2P^{\circ}_{0\frac{1}{2}} - 10s\ {}^2S_{0\frac{1}{2}}$
8850.4	4*h*	--------	----	11295.8	5.4	$7p\ {}^2P^{\circ}_{1\frac{1}{2}} - 11s\ {}^2S_{0\frac{1}{2}}$
8474.27	10*hl*	--------	----	11797.2	7.0	$7p\ {}^2P^{\circ}_{1\frac{1}{2}} - 10d\ {}^2D_{2\frac{1}{2}}$
8373.6	20*hl*	8376.5	10	11939.0	8.9	$7p\ {}^2P^{\circ}_{0\frac{1}{2}} - 9d\ {}^2D_{1\frac{1}{2}}$
8130.0	8*h*	--------	----	12296.7	6.6	$7p\ {}^2P^{\circ}_{0\frac{1}{2}} - 11s\ {}^2S_{0\frac{1}{2}}$
7815.80	10*hl*	--------	----	12791.1	0.4	$7p\ {}^2P^{\circ}_{0\frac{1}{2}} - 10d\ {}^2D_{1\frac{1}{2}}$
7678.93	2*h*	--------	----	13019.1	9.2	$7p\ {}^2P^{\circ}_{0\frac{1}{2}} - 12s\ {}^2S_{0\frac{1}{2}}$
7493.6	3*hl*	--------	----	13341.1	1.8	$7p\ {}^2P^{\circ}_{0\frac{1}{2}} - 11d\ {}^2D$
6713.80	300	--------	----	14890.59	0.8	$7s\ {}^2S_{0\frac{1}{2}} - 8p\ {}^2P_{0\frac{1}{2}}$
6549.84	1000	--------	----	15263.34	3.5	$7s\ {}^2S_{0\frac{1}{2}} - 8p\ {}^2P^{\circ}_{1\frac{1}{2}}$

TABLE 6. *Atomic energy levels of* Tl I

Electron configuration	Term symbol	J	Level value	Interval
			cm^{-1}	
$6s^2(^1S)\ 6p$	$6p\ ^2P^\circ$	0½ 1½	*0.0* *7792.7*	7792.7
$6s^2(^1S)\ 7s$	$7s\ ^2S$	0½	26477.5	
$6s^2(^1S)\ 7p$	$7p\ ^2P^\circ$	0½ 1½	*34159.6* *35160.8*	1001.2
$6s^2(^1S)\ 6d$	$6d\ ^2D$	1½ 2½	36118.0 36199.9	81.9
$6s^2(^1S)\ 8s$	$8s\ ^2S$	0½	38745.9	
$6s^2(^1S)\ 8p$	$8p\ ^2P^\circ$	0½ 1½	*41368.3* *41741.0*	372.7
$6s^2(^1S)\ 7d$	$7d\ ^2D$	1½ 2½	42011.4 42049.0	37.6
$6s^2(^1S)\ 5f$	$5f\ ^2F^\circ$	2½, 3½	*42318.4*	
$6s^2(^1S)\ 9s$	$9s\ ^2S$	0½	43166.2	
$6s^2(^1S)\ 9p$	$9p\ ^2P^\circ$	0½ 1½	*44380.9* *44562.5*	181.6
$6s^2(^1S)\ 8d$	$8d\ ^2D$	1½ 2½	44672.7 44692.7	20.0
$6s^2(^1S)\ 6f$	$6f\ ^2F^\circ$	2½, 3½	*44823.5*	
$6s\ 6p^2$	$6p^2\ ^4P$	0½ 1½ 2½	45219.8 49820. 53046.	4600 3226
$6s^2(^1S)10s$	$10s\ ^2S$	0½	45296.8	
$6s^2(^1S)10p$	$10p\ ^2P^\circ$	0½ 1½	*45939.3* *46043.6*	104.3
$6s^2(^1S)\ 9d$	$9d\ ^2D$	1½ 2½	46098.5 46110.3	11.8
$6s^2(^1S)\ 7f$	$7f\ ^2F^\circ$	2½, 3½	*46185.3*	
$6s^2(^1S)11s$	$11s\ ^2S$	0½	46456.2	
$6s^2(^1S)11p$	$11p\ ^2P^\circ$	0½ 1½	*46853.8* *46917.1*	63.3
$6s^2(^1S)10d$	$10d\ ^2D$	1½ 2½	46950.0 46957.8	7.8
$6s^2(^1S)\ 8f$	$8f\ ^2F^\circ$	2½, 3½	*47004.6*	
$6s^2(^1S)12s$	$12s\ ^2S$	0½	47178.8	
$6s^2(^1S)12p$	$12p\ ^2P^\circ$	0½ 1½	*47442.6* *47477.4*	34.8
$6s^2(^1S)11d$	$11d\ ^2D$	1½, 2½	47501.4	
$6s^2(^1S)13s$	$13s\ ^2S$	0½	47654.7	
$6s^2(^1S)13p$	$13p\ ^2P^\circ$	0½, 1½	*47847.7*	
$6s^2(^1S)12d$	$12d\ ^2D$	1½, 2½	47876.0	
$6s^2(^1S)14s$	$14s\ ^2S$	0½	47983.2	
$6s^2(^1S)14p$	$14p\ ^2P^\circ$	0½, 1½	*48129.6*	

TABLE 6. *Atomic energy levels of* Tl I—Continued

Electron configuration	Term symbol	J	Level value	Interval
			cm^{-1}	
$6s^2(^1S)13d$	$13d\ ^2D$	1½, 2½	48142. 3	
$6s^2(^1S)15s$	$15s\ ^2S$	0½	48223. 2	
$6s^2(^1S)15p$	$15p\ ^2P°$	0½, 1½	*48331. 2*	
$6s^2(^1S)14d$	$14d\ ^2D$	1½, 2½	48339. 3	
$6s^2(^1S)16s$	$16s\ ^2S$	0½	48399. 5	
$6s^2(^1S)16p$	$16p\ ^2P°$	0½, 1½	*48459. 5*	
$6s^2(^1S)15d$	$15d\ ^2D$	1½, 2½	48488. 6	
$6s^2(^1S)17s$	$17s\ ^2S$	0½	48534. 8	
$6s^2(^1S)16d$	$16d\ ^2D$	1½, 2½	48604. 0	
$6s^2(^1S)18s$	$18s\ ^2S$	0½	48639. 0	
$6s^2(^1S)17d$	$17d\ ^2D$	1½, 2½	48696. 5	
$6s^2(^1S)19s$	$19s\ ^2S$	0½	48726. 2	
$6s^2(^1S)18d$	$18d\ ^2D$	1½, 2½	48770. 5	
$6s^2(^1S)20s$	$20s\ ^2S$	0½	48796. 2	
$6s^2(^1S)19d$	$19d\ ^2D$	1½, 2½	48828. 6	
$6s^2(^1S)20d$	$20d\ ^2D$	1½, 2½	48878. 2	
$6s^2(^1S)21d$	$21d\ ^2D$	1½, 2½	48920. 6	
$6s^2(^1S)22d$	$22d\ ^2D$	1½, 2½	48957. 7	
$6s^2(^1S)23d$	$23d\ ^2D$	1½, 2½	48988. 9	
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Tl II $(^1S_0)$	*Limit*		**49264.2**	

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