

The Vacuum Spark Spectra of Some of the Heavier Elements, and Series Classification in the Spectra of Ionised Atoms Homologous with Copper, Silver, and Gold

J. A. Carroll

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IX. *The Vacuum Spark Spectra of Some of the Heavier Elements, and Series Classification in the Spectra of Ionised Atoms Homologous with Copper, Silver, and Gold.*

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(Communicated by H. F. NEWALL, F.R.S.)

(PLATES 4, 5.)

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§ 1. The vacuum spark spectra of the lighter elements have furnished, in the hands of MILLIKAN and BOWEN,* data for a remarkable extension of the field of optical series spectra. Their recognition and discussion of the sequence of doublet spectra of ionised atoms similar to lithium and sodium has emphasized certain difficulties in the interpretation of doublet separations which we shall mention briefly in § 4.

The writer has, by means of spectra photographed by him in Prof. MILLIKAN'S laboratory at the California Institute of Technology and in the laboratory of the Mount Wilson Observatory, essayed the extension of this work into the field of elements lying in the middle part of the periodic table.

* See papers by these writers in the 'Phys. Rev.' and 'Astroph. Jour.'; in particular, 'Phys. Rev.', September, 1924, and 'Phil. Mag.', May, 1925.

Sequences of spectra homologous with the spectra of copper, silver, and gold have been found, as set forth in the following group :—

Cu I,	Zn II,	Ga III,	Ge IV,
Ag I,	Cd II,	In III,	Sn IV,
Au I,	Hg II,	Tl III,	Pb IV,

Of these, Hg II, Ga III, In III, Tl III, Ge IV, Sn IV, Pb IV, are new. The vacuum-spark spectra of these elements are all very rich in lines, but few of which are included in the series groups. The wave-lengths of all the lines have been measured (with considerable accuracy for this region) and are tabulated at the end of this paper.

The general methods employed will now be described and followed by a discussion of the particular devices used and results obtained for each element separately.

§ 2. *The Methods of Exciting and Photographing the Spectra.*

Two distinct methods of excitation were used, according to the region of the spectrum under investigation. Both depend on obtaining between electrodes *in vacuo* a discharge of high current density, so that the chance of an electron impinging upon an atom already once or twice ionised is high.

In the region of wave-lengths less than 2300 Å.U., Prof. MILLIKAN'S vacuum spectrograph was used. This instrument is essentially that described by MILLIKAN and BOWEN in 'Phys. Rev.,' vol. 24, p. 209 (1924), and vol. 12, p. 167 (1918), and consists of a spark chamber and a concave grating of 1 metre radius mounted so as to return the spectrum nearly along the direction of the incident light to a Schumann plate, the whole apparatus being capable of exhaustion to a very low pressure. The spark was excited between suitable electrodes by means of an intermittent discharge from a battery of two to four half-gallon Leyden jars in parallel with a transformer yielding 2 to 3 kw. at 25,000 volts.

To obtain the spectra of wave-length longer than 2300 Å.U., Dr. ANDERSON'S condenser discharge *in vacuo* was used. In this method a condenser of rather less than 1 micro-farad capacity was charged to 20,000–25,000 volts and then discharged across a spark gap *in vacuo* between electrodes containing the element to be studied. The exposure was varied by regulating the number of sparks (one to each discharge). From 6 to about 400 sparks were used. In general, four exposures were made in the ratio of 1 : 4 : 16 : 64 for the purpose of obtaining an intensity scale.

The spectra were photographed together with a comparison spectrum of the iron arc on Eastman films, with the one-metre radius concave grating spectrograph of the Mount Wilson Observatory. A complete description of this apparatus, together with an account of the method of determining wave-lengths rapidly and accurately, and of establishing a logarithmic intensity scale, is given by J. A. ANDERSON in 'Astroph. Jour.,' vol. 59, p. 76, 1924. In both methods the gas pressure was so low that the spark gap could not be widened beyond 2 mm.

§ 3. *Methods of Measuring the Spectra and Determination of Wave-lengths.*

The negatives obtained with ANDERSON'S apparatus were measured on his direct reading measuring machine by comparison with the iron spectrum as described by him in the article referred to above. The accuracy of measurement depends somewhat on the character of the line and upon the standard wave-lengths available for adjusting the curve of corrections, but in general the error is less than $0\cdot03 \text{ \AA}$.

The negatives on Schumann plates obtained with the vacuum spectrograph were dealt with in different ways depending upon the presence or absence of already well-known lines (*e.g.*, due to impurities accidentally or purposely introduced). If no known lines were available, the necessity arose of obtaining new local standards of short wave-length by indirect comparison with the iron spectrum through the second or third order spectra.

The first method (Method A) was used when the number of known lines present was sufficient to determine an accurate curve of corrections. Some plates were measured on a Gaertner, and some on a Zeiss comparator, and approximate wave-lengths were calculated on a Monroe or Brunsviga machine.

The impurities present were usually N, O, C, Al, H, and the lines due to them could be identified without much trouble; the approximate wave-lengths found for them were then compared with a list of standard wave-lengths (Table VIII, p. 394) determined from measurements in high orders by Mr. I. S. BOWEN, which are believed to be in error by not more than $0\cdot05 \text{ \AA.U.}$, whence a curve of corrections could be drawn, and afterwards adjusted, by re-distributing the errors found, by means of determinations in the second or a higher order.

The general results are accurate to $0\cdot2 \text{ \AA.U.}$, when no second order determinations are available, or if the lines are measured on one plate only, but may be much more accurate if the measures in the second or a higher order are available.

The second method (Method B) was used when the electrodes consisted of the pure metal, and so no, or very few, impurities were present to yield standard lines.

Previous measures by other writers of the extreme ultra-violet spectra of the elements considered in this paper cannot, in general, be used as sources of standards to reduce measurements to wave-lengths in the region below $\lambda 2000 \text{ \AA.U.}$, because they are rarely sufficiently accurate. They have been determined sometimes from the investigation of so small a region of wave-lengths that comparison with other standards could not be made, and sometimes a correction curve employing too few standard lines has been used. The method employed by the present writer was one of systematic comparison of high-order measures of lines of the shorter wave-lengths with first-order measurements of the longer wave-lengths. A few of these lines of longer wave-lengths were present on the plates taken with the Anderson apparatus, and hence could be determined accurately by comparison with the spectrum of the iron arc. Thus a few lines in the region $\lambda\lambda 2300\text{--}2600 \text{ \AA}$. were determined by comparison with

the standard iron spectrum, these lines being also present on a plate from the vacuum instrument covering the region $\lambda\lambda$ 1400–2800 Å. A few standards of short wave-length in the region 1150–1300 Å.U. were then obtained from lines in second-order positions close to the primary standards, and from a plate containing these in the third-order (3450–3900) lines between λ 1725 and λ 1950 Å.U. were found in the second order, and lines near 1000 Å. in the fourth order.

Interpolations between, and small extrapolations from, standards close enough together were then carried out, and the results from different orders made to agree by distributing the errors found. Finally, weighted mean values were assigned to all available lines (the weights being proportional to the order of spectrum in which the line was measured), and final correction curves made, which could be drawn with considerable accuracy.

This process as described was carried out in full for Thallium only, and a few further details will be added in the section dealing with that element. The process is laborious, and takes a good deal of time, but the results are found to be very accurate whenever an independent test can be made. Sometimes a combination of methods A and B were used as in the work on Gallium.

It is to be noted that no attempt was made to force the measured values of standard lines into exact agreement with their supposed true wave-lengths, but a smooth curve of corrections following the fixed points as well as possible was used. The errors in the final corrected values of the measured positions of the standard lines can therefore be taken as an indication of the accuracy of measurement, since in drawing the correction curve the preferential treatment accorded them was to a large extent smoothed out.

The agreement between measurements of the wave-length of a line found in two or more orders also furnishes a measure of accuracy. In the tables at the end of this paper mean values of the wave-lengths are shown, together with the measures in the various orders, so that an estimate of the accuracy of measurement may be made in this way. Lines supposed due to impurities are always included to enable the reader to make his own estimates or to make any corrections future data may afford.

§ 4. *The Classification of Series Lines and the Calculation of Term Values.*

There is a great difference between the problem of identifying series lines in spectra of the type dealt with in this paper, and that of arranging the lines in ordinary arc or spark spectra.

First of all, the outstanding guides, used in the classification of arc lines (such as reversals of lines, temperature classifications by KING's method, ionisation or resonance potentials), are not present to mark out certain lines as belonging to particular series, nor do the lines show any well-marked differences of character in definition.

Furthermore, for two reasons, the law of the constancy of separation in wave number

between lines arising from the same pair of levels is of less value than in ordinary spectra. The series, in the first place, are scarcely series at all in the true sense of the word, because only the first members of any series can with certainty be identified, the remainder being so faint as not to appear or else inextricably mixed up with the enormous number of lines in these spectra.

Secondly, one is not, as a rule, able to search for a frequency difference constantly repeated within at most one unit of wave-number, for, owing to the shortness of the wave-lengths concerned and the inevitably somewhat large errors of measurement, one rarely can expect a measured separation to be within ten or twenty units of its true value. Thus, while it is not difficult to find many pairs with the same separation within these limits, they are only too likely to be fortuitous. This is not to say that such a clue is useless, but only that it must be received with caution and considered in relation to other evidence. By way of illustration, let us consider a pair of lines at λ 1200 Å and λ 1600 Å, the error in measurement being certainly < 0.1 Å in each. This means that the wave-numbers are $83,333 \pm 7$ and $62,500 \pm 4$ —*i.e.*, the separation may be in error by ± 11 units owing to the fact that an error $d\lambda$ produces an error $d\nu = d\lambda/\lambda^2$. Thus the values of a doublet separation between two pairs of lines accurate to 0.1 Å may differ by ± 20 units.

The richness in lines of these spectra is another source of difficulty. The spectra are not pure or even easily separable into their constituents as are ordinary arc or spark spectra, but contain lines due to the un-ionised element (though to a negligible extent) and lines due to the element in the first, second, third, fourth, and even higher stages of ionisation.

Since the series are not extended far enough, we are not able to use formulæ of the Rydberg type for the calculation of limits or terms, and to check our results; nor is there an opportunity to avail ourselves of combination lines, since these, while they are to be expected in the very intense electric field in the spark, are too faint to be detected or measured with the requisite accuracy.

It is likely that methods may be developed whereby spectra due to the successive stages of ionisation of an atom may be produced—if not individually, at least successively by increasing stimulation, as, for instance, a method that occurs to one of bombarding a stream of vapour *in vacuo* with a very dense stream of appropriately accelerated electrons. However, at present we have to rely upon the methods to be described for the identification of series lines. These differ much in kind and, at present, in conclusiveness, from those used for spectra corresponding to lower stages of excitation.

The results of MILLIKAN and BOWEN, of A. FOWLER, of PASCHEN, and of others, on the doublet spectra of sodium and lithium-like atoms form the basis of the method. The approximate positions of the lines are located by extrapolation from the already known spectra of the first and second stages of excitation, and further identification is effected by such considerations as intensity relations, doublet separations, and sometimes the variation of the lines with different conditions of excitation. The main method

used follow very closely those of MILLIKAN and BOWEN, but additional criteria are often used.

We expect, and find, that the spectra will follow the displacement law of KOSSEL and SOMMERFELD and consist of doublet systems like those of copper, silver, and gold. Indeed, if this were not so it would scarcely be possible to identify the lines without further experimental data.

The first pair of the principal series is the easiest to identify, *i.e.*, the lines $1s - 2p_1$ and $1s - 2p_2$. If the same conditions obtain in these elements as in those investigated by MILLIKAN and BOWEN,* the vacuum spark should exhibit the pair of lines $1s - 2p_1$, $1s - 2p_2$ as among the strongest lines on the plate, and this is found to be so. Also, there will be a linear progression in wave number for the line $1s - 2p_2$ as we proceed from one element to the next in order of atomic number, the atom being supposed in a state once further ionised at each step.

MILLIKAN and BOWEN point out that this rests upon SOMMERFELD's† derivation of the X-ray doublets. Thus

$$\frac{\nu}{R} = \left(\frac{Z - \sigma}{n_a + n_r} \right)^2 + \left(\frac{1}{4} + \frac{n_r}{n_a} \right) \alpha^2 \left(\frac{Z - s}{n_a + n_r} \right)^4 \dots \dots \dots (1)$$

where R is RYDBERG'S number, taken to be 109,737·0 in the present work, Z the atomic number n_a , and n_r the azimuthal and radial quantum numbers respectively, α a constant, σ and s screening constants. We consider only the first term, giving σ different values σ_1 and σ_2 for the s and p level respectively, and obtain that

$$1s - 2p_2 = 2 \frac{\sigma_1 - \sigma_2}{n^2} \left(Z - \frac{\sigma_1 + \sigma_2}{2} \right) R, \dots \dots \dots (2)$$

i.e., the wave number of the first line of the principal series is a linear function of the atomic number. This is the so-called irregular doublet law.

We see, then, that the difference in level is supposed to be mainly due to a deeper penetration into the atom-core of the electron describing the more excentric orbit.

We may note, also, the other consequence of equation (1) for the irregular doublets. We have, taking the square roots,

$$\frac{1}{\sqrt{R}} (\nu_1^{\frac{1}{2}} - \nu_2^{\frac{1}{2}}) = \frac{\sigma_2 - \sigma_1}{n} \dots \dots \dots (3)$$

That is that, proceeding along the sequence A I, A II, A III, the value of $\sqrt{1s} - \sqrt{2p}$ should remain constant if the screening constants do not vary.

The degree to which these laws 2 and 3 are obeyed may be seen from Tables I, II, V, VI and VII, and fig. 1, which show the results obtained in this paper.

* 'Phys. Rev.,' vol. 24, pp. 209 *et seq.* (1924).

† SOMMERFELD. 'Atomic Structure and Spectral Lines,' 3rd edn., p. 509.

We shall return to this matter presently, in explaining the use of the calculation of levels by the method of HARTREE. Since the wave numbers of the lines involved are large, compared to $2p_2 - 2p_1$, an approximately linear law obtains for $1s - 2p_1$, but the proper guide to its position is the separation between the $2p_1$ and $2p_2$ levels, which can be calculated according to MILLIKAN and BOWEN'S use of Sommerfeld's fourth-power law for the X-ray doublets, viz., that the separation is given by

$$\Delta\nu = \xi \left(\frac{Z-s}{n} \right)^4 \dots \dots \dots (4)$$

where Z is the atomic number, s a "screening constant" representing the shielding effect on the nuclear field of the inner electrons, n the total quantum number, and ξ is a known constant. This formula is obtained from SOMMERFELD'S theory of the "relativity doublet" and represents the difference due to the relativity of mass, in the energy of two orbits of the same total quantum number but different azimuthal quantum number (*i.e.*, in equation (1), s and σ are constant, n_a and n_r vary).

In MILLIKAN and BOWEN'S* method of using this expression s is calculated from the experimental data, and it is found that, as Z increases by unity, s very soon becomes nearly linear, so that one can use the formula to calculate values of $\delta\nu$ for a new Z by a nearly linear extrapolation to a value for s .

They point out* that the acceptance of this formula as representing the results, and that the mechanism of the separation law is really relativity, involves serious difficulties. Thus, in an atom whose outer electron is, on the basis of the usual ideas, normally in a $1s$ orbit (*e.g.*, in BOHR'S notation 2_1) and in which the two p orbits are 2_2 , then the difference $2p_2 - 2p_1$, is to be explained on the basis of a variation in orientation of the orbits with respect to the main body (the core or *rumpf*) of the atom, and the difference $2_1 - 2_2$ is supposed due to the greater ellipticity of the 2_1 orbit, which causes it to penetrate more deeply into the central parts of the atom, and so experience a stronger field than does the electron in a 2_2 orbit.

If, however, we are to accept the difference $2p_2 - 2p_1$ as due to a relativity of mass, then we must have the $2p_2$ orbit as 2_1 and the $2p_1$ orbit as 2_2 , and the $2s$ orbit must also be 2_1 , so we are left with the task of explaining not only the now forbidden combination $2s - 2p_2$ (*i.e.*, $2_1 - 2_1$), but also the large difference in energy observed (many times greater than $2p_2 - 2p_1$) as due to a difference in orientation, or, at any rate, some third quantizable variable. The dilemma is fully expounded in the paper quoted, and we need not enter into it further here. The variation of s with Z in the elements considered in this paper may be seen from Table III and fig. 2.

It remains to mention the modification of SOMMERFELD'S formula for the X-ray doublets (4) introduced by LANDÉ,† for the purpose of justifying its application to optical spectra. LANDÉ takes account of the idea that p orbits dip into the inner part

* *Loc. cit.*

† A. LANDÉ, 'Zeit. f. Physik,' vol. 25, p. 46 (1924).

of the atom during their description, and assuming that the doublet separation arises in the inner part of the orbit he derives a correcting factor to the X-ray law.

His result, then, is that if $\Delta\nu = 2p_2 - 2p_1$,

$$\Delta\nu = \alpha \frac{C^2 R (Z - s)^2}{n_a^3 (k) (k - 1)} \dots \dots \dots (5)$$

where C is the core charge = 1, 2, 3, etc.

R the Rydberg number, $n_a = m =$ effective quantum number,

α ,, relativity constant, $k =$ azimuthal quantum number.

Z = atomic number, and s is a screening constant.

It is not so convenient for our purpose as equation (4), since (4) gives an extrapolation formula involving s only as unknown and not m as well. We know n independently, but m depends on the absolute value of a term, and so cannot be found till the spectrum is completely identified, and thus rule 4 is more convenient than rule 5, which we will discuss in a later section.

We will now explain briefly the application of HARTREE'S* theoretical investigations on the spectra of atoms like those of sodium and lithium.

He develops formulæ for term values of two kinds, which can be used for extrapolation into new spectra. One type of expression gives the law of progression of the energy of orbits of considerable eccentricity which penetrate well into the core of the atom; the other type is concerned with orbits lying wholly outside the core. For the sake of illustration the law of progression of energy levels belonging to penetrating orbits may be considered. It is shown that if q is the quantum defect, defined as the difference between the total quantum number n of the orbit and the Rydberg denominator m of the term value ($\nu = C^2 R/m^2$), then $1/q$ tends to progress linearly with Z as C increases. (See Tables V, VI, VII.) This result is used for the present purpose by extrapolating from known values of $1/q$ and then calculating ν . We can then establish the principal pair very definitely, and the process of finding the diffuse, fundamental and other pairs and satellites, is very similar, but less definite on the whole.

With some clues as to the position of the lines, and knowing the $p_2 p_1$ separation, the pair $2p_1 - 2s$ and $2p_2 - 2s$ may next be looked for, but, both on account of its position far down in the ultra-violet, and on account of its comparative faintness, it is somewhat difficult to identify, especially so since the accuracy of measurement becomes of vital importance in this region, because an error $d\lambda$ produces an error $d\nu = d\lambda/\lambda^2$ in the wave number.

Accordingly, I have usually sought the diffuse triplet (doublet and satellite) next, being guided in its identification by extrapolation methods of guessing the positions and separations of its components and by intensity relations. The $2p_2 - 2p_1$ separation is

* D. R. HARTREE, 'Roy. Soc. Proc.,' A, vol. 106, p. 552 (1924).

between the line of shortest wave-length ($2p_2 - 3d_2$) and the line of longest wave-length ($2p_1 - 3d_1$), *i.e.*, the satellite of the $2p_1 - 3d_1$ line and much the weakest of the three.

The correctness of this identification, which gives the $3d_2 - 3d_1$ separation, is tested by searching for the "fundamental" pair $3d_1 - 4f$, $3d_2 - 4f$; it is capable of fairly precise location, and is in a region where the required accuracy of measurement is more easy of attainment. It has not always been possible to proceed so far as this with the certainty one would desire, but sometimes I have been able to go on to the "super-fundamental" series $4f-5g$, and so obtain further checks, especially if the doubling of the f level is detectable.

A suggested new rule of doublet separations for the orbits lying outside the core will be described in § 6.

It will be more profitable to discuss each case on its own merits rather than to go into more detail here, so the various peculiarities will be discussed afterwards. All the methods available were used in identifying lines, including such crude guides as simple graphical extension of curves of wave number plotted against atomic number. Zeeman effect would be of great value as confirmatory evidence, but would be less useful at an earlier stage; but this test was not available.

Finally, the assignment of definite term values was made. This could be done because it was possible to extend the series groups far enough to include lines arising from transitions between the f or g levels and earlier ones. Now these outer orbits are found to have values in the spectra of Cu I, Ag I, Zn II and Cd II, very nearly the same as those corresponding to 4_4 and 5_5 orbits in a simple Coulomb field. So we conclude that they are circular orbits of the type found in the hydrogen atom and named hydrogenic by H. N. RUSSELL. The presumption is, then, that this will be true of the corresponding orbits in the other elements investigated. Thus a plausible value of the outermost available level was estimated by any method, the safest rule probably being to increase the energy of the corresponding orbit in the last known spectrum in the sequence by a small amount, being guided by the known increments such as one can see in other spectra, *e.g.*, in Paschen's work on Aluminium. The result of this cannot be much in error if our assumption is correct, and a check is afforded by the resulting value of the d or f levels. For if we know, say, the $4f - 5g$ line and assign a value to $5g$ arbitrarily, then $4f$ is directly calculable, and if it is nearly hydrogenic we can rest satisfied with our assumption. Whatever error we may have made will of course affect all terms equally in wave number, but the practical importance of the greatest error likely is very small in its effect on the large values of the S and p levels. The values of the ionisation and resonance potentials are then very accurately determinable from the spectroscopic data.

§ 5. *The Spectra Obtained.*

Mercury.—The vacuum spark spectrum of mercury was photographed with the vacuum spectrograph between wave-lengths λ 700 Å.U. and λ 1760 Å.U.

A stiff paste of mercury oxide and dilute nitric acid was packed into short pieces of

aluminium tubing and allowed to harden. These formed the electrodes. In this way lines due to oxygen, nitrogen, aluminium, and carbon were present and served as standards to reduce the spectrum. The plate was measured on ANDERSON'S direct reading machine, and the correction curve made by using the known wave-lengths due to the impurities present, and re-corrected by aid of such lines as were present in more than one order.

The errors in the wave-lengths are in general less than 0.1 \AA.U. , and the agreement with LYMAN'S* measures over the region in common is within this limit, except for four lines, namely:—

1321.0 (L. 1321.4); 1400.6 (L. 1400.4); 1481.4 (L. 1481.6); 1495.3 (L. 1495.0).

The measured values of the standard lines agree very well with the true values, as can be seen from Table IX.

The spark, though somewhat feeble to the eye, was very strong in the far ultra-violet and the strongest lines on the plate were all solarised. There was also rather more general fogging of the plate than usual, so that the intensity scale is probably somewhat compressed.

It is possible that some of the lines listed in Table IX. are second-order positions of lines of wave-length less than 700 \AA.U. , but this is rather unlikely, because the reflecting power of the grating fell off very rapidly below this point.

The Spectrum of Ionised Mercury (Hg. II.).—V. THORSEN'S publication of a series arrangement of the spectrum of gold (Au I),† and the data derived in the present paper, were serviceable in an attack upon the spectrum of ionised mercury.

TABLE A.—The spectrum of Ionised Mercury. Hg II.

λ I.Å.	ν	$\delta\nu$			m	n_k
1,649.85*	60,612	9,127	$1s - 2p_1$	$1s = 153,701$	1.6899	6_1
1,942.3*	51,485		$1s - 2p_2$			
2,260.35	44,227	9,121	$2p_2 - 2s$	$2s = 57,984$	2.7514	7_1
2,847.67	35,106		$2p_1 - 2s$			
2,252.94	44,373	562	$2p_1 - 3d_2$	$2p_1 = 93,090$	2.1715	6_2
24.75	935		$- 3d_1$			
1,869.4*	53,493	9,120	$2p_2 - 3d_2$	$2p_2 = 102,210$	2.0723	6_2
4,960.43	20,153.9	563.1	$3d_1 - 4f$	$3d_1 = 48,154$	3.0192	4_3
4,825.62	20,717.0		$3d_2 - 4f$	$3d_2 = 48,717$	3.0017	4_3
Assumed value of $4f = 28,000.$						4_4

* λ vac.

* T. LYMAN. 'Astroph. Jour.,' vol. 38, p. 282 (1913).

† V. THORSEN. 'Die Naturwissenschaften,' vol. 25, p. 500 (1923).

RYDBERG* had noted a pair of lines in the spark spectrum of mercury apparently analogous with the principal pairs of ionised zinc and cadmium at wave-lengths $2847\cdot83 \text{ \AA}$ and $2226\cdot82 \text{ \AA}$, with a wave number separation of $\Delta\nu = 9829\cdot3$. The present writer was, however, unable to make any progress on this basis, but the law of progression of the line $1s - 2p_2$ indicates that since $1s - 2p_2$ of Au I is at $\nu = 37,359$, $1s - 2p_2$ of Hg II is likely to be near $\nu = 52,000$ (see Table II, page 379). Moreover, the existence of a line at $\lambda 1942\cdot3$ in Hg and of another at $\lambda 1558\cdot60$ in Tl indicates that $\lambda 1942\cdot3$ is the less refrangible member of the 1st principal pair of Hg II. The companion ($1s - 2p_1$) is the line $\lambda 1649\cdot8$ recorded also by LYMAN and by WOLFF, which is strong in the arc and spark in air, and in the spark *in vacuo*. This yields a value for $2p_2 - 2p_1$ of 9128. There is no means of predicting at all accurately where $2p_2 - 3d_2$ will lie, but that it is to be expected in the region of 1850–1900 \AA , we may see by extrapolating values of $1s$ and $2p_1$ and $2p_2$ which can be adjusted (in the manner shown for Sn IV) by means of the already discovered doublet, and, assuming $3d$ about 48,000, we get an indication of the region to be searched.

Thus the strong line at $\lambda 1869\cdot4$ soon shows itself as the line $2p_2 - 3d_2$, with lines at $\lambda\lambda 2224\cdot75$ and $2252\cdot7$ as companion and satellite.

The d separation is somewhat large, but is probably correct, as further search reveals a pair at $\lambda 4760$ and $\lambda 4824$ as a $3d_{12} - 4f$ pair, with the appropriate separation. The location of the $2p - 2s$ pair confirms the results, both by the value of the separation and the value of $2s$, which is to be expected to be $>3d$ and falls well into place in Table VII. A value of 28,000 was assigned to the $4f$ term, and the other terms were calculated from this. This assignment is made on the similarity of the spectrum to that of Zn and Cd, where such a value appears correct. A direct comparison with $4f$ for gold is not possible. Table I shows the reasonableness of this assumption.

The assumed value is not likely to be in error by more than a hundred units, so the other levels are also accurate to the same extent. Independent confirmation of the results comes from a measurement by SMYTH, who finds doubly-charged mercury ions appearing at about 19 volts,† while the ionisation potential of Hg II is here found from $1s$ to be 19·0 volts. Also the lines are among those tabulated as belonging to the second stage of excitation as shown by the electrodeless discharge method developed by L. and E. BLOCH.‡ Furthermore, the recent work of L. A. TURNER and K. T. COMPTON§ on the absorption of light by ionised atoms of mercury supports these conclusions very strongly. They find $\lambda 1942$, absorbed by the positive ions in a low-voltage arc in mercury vapour; this indicates that it is one of the lines starting from the lowest level in the atom, which it is taken to be in this paper (*i.e.*, $1s - 2p_2$). The

* A. FOWLER. ‘Report on Series in Line Spectra,’ p. 151.

† H. D. SMYTH. ‘Roy. Soc. Proc.,’ A, vol. 102, p. 283 (1922).

‡ L. and E. BLOCH. ‘Comptes Rendus,’ vol. 176, p. 833 (1923); ‘Jour. de Phys. et le Rad.,’ vol. 4, p. 333 (1923).

§ ‘Phys. Rev.,’ vol. 25, p. 613 (1925).

other member of the principal pair is outside the range of their experiments. They find $\lambda\lambda$ 2225 and 2848 are not absorbed, which is to be expected, and that their excitation potentials are much higher than is that required to produce the 1942 line. This agrees with these two lines being members of subordinate series. I am very grateful to these writers for informing me of their result before publication, and for their courtesy in this matter.

The lines used in the series classification which are not included in Table IX are to be found in KAYSER'S 'Handbuch,' and the measures by STILES* have been used when available.

Gallium.—Electrodes were used made of aluminium amalgamated with pure metallic gallium, which melts at about 30° C. Two plates were obtained with the vacuum spectrograph, one covering the region from λ 500 Å to λ 1900 Å, and another from λ 1400 Å to λ 2800 Å. A third negative containing four exposures in the ratio of 1 : 4 : 16 : 64, together with an iron comparison spectrum, was taken with Dr. ANDERSON'S apparatus. In this last plate the lines due to gallium could be distinguished from those due to aluminium by the fact that the lines due to the latter element grew progressively stronger with increasing exposure, whereas, owing to the gradual consumption of the gallium amalgamation of the electrodes, the lines due to gallium at first increased and later decreased in intensity with increasing exposure.

The reduction of the measurements of the SCHUMANN plates to wave-lengths was effected by aid of the aluminium lines present and certain impurities (*e.g.*, C, O, N) and it was further checked by certain lines in common with the negative obtained by the condenser discharge which was measured by comparison with the iron spectrum. That is to say, a combination of Methods A and B was used. Very satisfactory agreement was obtained between measures on different plates and a general accuracy of about 0.1 Å can be claimed. Where several measures in different orders exist the accuracy is higher than this.

Few measures by other writers of the vacuum spark spectrum of gallium exist, but the recent ones by M. WEINBERG† must be mentioned, since the agreement with the present writer is not complete. Some of the lines tabulated by WEINBERG as belonging to gallium are due to impurities, usually aluminium (*e.g.*, the 1760 group of Al), as will be seen by comparison with Tables VIII and X at the end of this paper. It is possible that the stage of excitation reached in M. WEINBERG'S experiments was not so high as was reached with MILLIKAN'S apparatus. This would account for the presence or absence of certain lines not common to the two lists. The most remarkable feature is the absence of the line λ 1495.4 in the list of wave-lengths published by WEINBERG. This is the short wave-length member ($1s - 2p_1$) of the principal pair, according to the present work, and should be present in her spectra, since they contain λ 1534.6, which is its companion ($1s - 2p_2$), as a strong line.

* H. STILES. 'Astroph. Jour.,' vol. 30, p. 48 (1909).

† M. WEINBERG. 'Roy. Soc. Proc.,' A, vol. 107, p. 138 (1924).

There is a strong line in the nitrogen spectrum at λ 1494·78, but that this should have been confused by me with the gallium line is scarcely possible. The resolving power of the apparatus would clearly separate the two lines were they both present, but only one line is seen. This cannot be the nitrogen line, for, even were the difference in position within the errors of measurement, the intensity is too high for it to be due to anything but gallium or aluminium. It is certainly not the latter, and, furthermore, there are other stronger lines in the nitrogen spectrum taken with this apparatus (see Table VIII), and even they are not certainly present.

The Spectrum of Ga III.—The spectrum of doubly-ionised gallium (Ga III) resembles that of Cu I or Zn II, and consists of fairly close doublets.

TABLE B.—The spectrum of Doubly-Ionised Gallium. Ga III.

λ I.Å.	ν	$\delta\nu$			m	n_k
1,495·36*	66,874	1,713	$1s - 2p_1$	$1s = 247,797$	1·9964	4_1
1,534·65*	65,161		$1s - 2p_2$			
1,323·17*	75,576	1,720	$2p_2 - 2s$	$2s = 107,064$	3·0374	5_1
1,353·98*	73,856		$2p_1 - 2s$			
1,295·29*	77,203	109 1,712	$2p_1 - 3d_2$	$2p_1 = 180,923$	2·3364	4_2
93·46*	312		$- 3d_1$			
1,267·19	78,915		$2p_2 - 3d_2$	$2p_2 = 182,636$	2·3254	4_2
2,424·96*	41,237·8	107·6	$3d_1 - 4f_1$	$3d_1 = 103,609$	3·0874	4_3
2,418·65*	41,345·4		$3d_2 - 4f_2$				$3d_2 = 103,721$	3·0858	$4_3$
(4,380·67)†	22,821·2	6·2	$4f_2 - 5g$	$4f_1 = 62,370$	3·9793	4_4
(4,381·86)†	22,815·0		$4f_1 - 5g$				$4f_2 = 62,376$	3·9791
Assumed value of $5g = 39,555$						5_5

* λ vac.

† See p. 370.

Simple extrapolation by the linear law for the line $1s - 2p_2$ from the corresponding lines in Cu I and Zn II, yielded (see Table II) 1534·6 as this line, and also the pair λ 1495·36 and λ 1534·6 stand out as two very strong lines, probably the first principal pair. (In Plate 4 this pair is illustrated and marked.) The confirmation of this lies in the doublet separation, which is 1714 units, and fits in well with the values for Cu I and Zn II (Table III). The identification of the diffuse doublet and satellite and of the fundamental pair proceeds exactly in the manner above described (§ 4).

It will be seen from the table that the doublet separation of the $3d - 4f$ pair is less than that of the corresponding separation of the diffuse line and satellite. This suggested the possible existence of a satellite to the fundamental pair, and consequently a doublet for the line $4f - 5g$.

The mean value of the p separation seems to be about 1715, and the errors of measurement would easily allow $2p_1 - 3d_2$ and $2p_1 - 3d_1$ to be separated by 114 wave number units. If the arrangement suggested is correct, there should be a faint companion to $\lambda 2424.96$ (or perhaps to $\lambda 2418.65$), making the true d separation 114. This line $3d_1 - 4f_2$ would be at about $\lambda 2425.7$, but no trace of such a line could be found, and though in the second order of the plate taken with Anderson's apparatus a possible companion appears, it cannot be found in the first order.

There are, however, some reasons for believing the arrangement proposed for the $d - f$ and $f - g$ lines to be correct. First, I could find no other more suitable lines within any reasonable distance of these lines. Secondly, the separations are satisfactory, and the resulting term values agreeable, as may be seen from the tables and figures. Moreover, in Al III and other spectra in this paper there are corresponding strong lines similar to these.

The measures are, unfortunately, not accurate enough to furnish a decisive test, but in the spectrum of Tl III, where much greater accuracy can be obtained, a similar state of affairs seems to exist, and may do so also in Pb IV. It is, however, conceivable that the f level is single.

The acceptance of the $4f - 5g$ pair as being correct rests upon its separation, and upon the value of $4f$ yielded on assignment of the value of 39,555 to $5g$. That this value for $4f$ is satisfactory will be seen from the Tables I and V).

The other term values are in good accord with expectation, and from the $1s$ term a good estimate of $2s$ was made, which resulted in the location of the $2p - 2s$ pair. It is to be remarked that the combination rules between the d and f terms seem to be the same as that between the p and d terms, and not anomalous. The term values have been calculated by assigning a value to $5g$ somewhat higher than that for Al III (see Table I), and the values of the remaining terms are satisfactorily in accord with the other spectra. In Table B the second place in the wave-lengths has been retained simply for the sake of obtaining any benefit there might be. The accuracy of measurement is not, of course, 0.01 Å.

Indium.—Electrodes were used made of aluminium tubing filled with metallic indium. Two plates were taken with the vacuum spectrograph, one covering the region $\lambda 600$ Å to $\lambda 1900$ Å, and another covering $\lambda 1400$ Å to $\lambda 2800$ Å. One plate was obtained with Dr. ANDERSON'S vacuum spark apparatus. Unfortunately, very little indium was available, and only the stronger lines could be obtained by the condenser discharge method.

The general procedure was the same as that for gallium, except that the Schumann plates are reduced entirely on their own merits (method A) and not corrected by

intermediate comparison with an iron spectrum. The usual standard lines (Al, C, O, N) were used in obtaining the correction curve and the general accuracy is the same as for gallium. The remarks that were made under the heading "Gallium" apply to the results on indium obtained by WEINBERG,* except that both the lines of the principal pair of In III are recorded by her, and the general agreement is better.

The lines are given in Table XI.

The Spectrum of In III.—Extrapolation from the $1s - 2p_2$ lines of Ag I and Cd II confirms the lines picked out by inspection as the principal pair. The linear law gives λ 1748.8 as $1s - 2p_2$, and adopting λ 1625.3 as $1s - 2p_1$ one finds a doublet separation of 4345 units agreeing with the fourth-power law very well. (See Table III, p. 382.) Plate 4 shows the position of this doublet in the spectrum. The $2p - 2s$ pair could not be located with certainty. The position of the $2p - 3d$ pair and satellite seems satisfactory and the doublet separation $2p_2 - 2p_1$ agrees with that from $1s - 2p_{12}$ within the limits of error.

TABLE C.—The spectrum of Doubly-Ionised Indium. In III.

λ I.Å.	ν .	$\delta\nu$.			m .	n_k .
1,625.3*	61,527		$1s - 2p_1$			
1,748.8*	57,182	4,345	$1s - 2p_2$	$1s = 225,690$	2.0919	5_1
1,494.0*	66,934	284	$2p_1 - 3d_2$	$2p_1 = 164,164$	2.4528	5_2
87.7*	67,218		$-3d_1$			
1,403.07*	71,272	4,338	$2p_2 - 3d_2$	$2p_2 = 168,506$	2.4210	5_2
3,008.31	33,231.6		$3d_1 - 4f$	$3d_1 = 96,952$	3.1917	4_3
2,982.93	33,514.3	282.7	$3d_2 - 4f$	$3d_2 = 97,234$	3.1871	4_3
Assumed value of $4f = 63,720$						4_1

* λ vac.

The fundamental pair has been located and confirms the $p - d$ pair quite well, though its identification rests mainly on the doublet separation. No trace of a satellite could be detected, and the $4f - 5g$ pair could not be located. The term values are based on an assumed value for $4f$ (see Table I) of 63,720.

The intensity relations in the $p - d$ group are satisfactory, but this group and the $d - f$ pair stand or fall together. The d separation agrees with the law developed in § 6 and the term values are satisfactory. No alternative lines exist which agree well with the other spectra.

* M. WEINBERG, *loc. cit.*

Thallium.—Electrodes of metallic thallium were used. The spectrum is very rich in lines. They have been measured in several orders over a large range (λ 900 to λ 5500) and the wave-lengths tabulated are very accurate. The special method of reduction employed has been described above, § 3.

Plates were taken on the vacuum spectrograph covering in three plates the region λ 900–1900, 1400–2800 and 2900–4300, and a negative obtained by ANDERSON'S condenser discharge *in vacuo* covers from λ 2300 to λ 5500. Four exposures of the condenser discharge were made in the ratio 1 : 4 : 16 : 64 for the purpose of obtaining an intensity scale. An iron comparison spectrum was photographed also on this negative.

It is hoped that the very great accuracy obtained in these measures may prove useful to other spectroscopists working in these regions, since thallium is easily obtained and is a convenient source of lines. No other element gives so many lines that are known with such exactness. There have been several other measurements of the spectrum of thallium in the arc *in vacuo* and in the spark *in vacuo*, the most recent and complete of which are those of LANG,* who tabulates also the measures of previous workers. Though his apparatus was similar to mine his resolving power seems to have been very low, and his standard lines are probably not so accurate. Thus, the carbon pair given by BOWEN (Table VIII) at λ 1334·54 and λ 1335·72 are given by him as one line with wave-length ranging from λ 1335 to λ 1335·8 on different plates. Table XII shows these lines determined from my thallium spectra by indirect comparison with the iron arc as having mean wave-lengths λ 1334·59 and λ 1335·78, the extremes of variation being $< 0\cdot1$ Å.

Thus :

1st order.	2nd order.	3rd order.	Mean.
1334·53	34·60	34·60	1334·59 \pm ·03.
35·87	35·78	35·77	1335·78 \pm ·04.

Of the series lines, 1476·94 is given by LANG as 1478·2.
 1558·60 is given by LANG as 1559·3.
 1231·57 is not given by LANG.
 1506·21 is not given by LANG.

The Spectrum of Tl III.—The identification of lines in this spectrum rests to some extent on that in Hg II and *vice versa*, and both receive support from the results for Pb IV. The extrapolation to λ 1558·60, as the line $1s - 2p_2$, is scarcely open to doubt (see Table II). The identification of $1s - 2p_1$ was much more difficult on account of the great number of strong lines in this spectrum. However, as the result of many trials, the line λ 1266·33 remains as the only satisfactory companion. The doublet separation found is satisfactory (see Table III), but on account of its magnitude it is not quite so precisely predictable as those for Ga III and In III. Its confirmation depends more strongly on its agreement with the value obtained from the diffuse group. The accuracy

* R. J. LANG, 'Phil. Trans.,' A, vol. 224, p. 371 (1924).

TABLE D.—The spectrum of Doubly-Ionised Thallium. Tl III.

λ I.Å.	ν	$\delta\nu$			m	n_k
1,266·33*	78,968	14,808	$1s - 2p_1$	$1s = 248,045$	1·9954	6_1
1,558·60*	64,160		$1s - 2p_2$			
			$2p_2 - 2s$	$2s =$		7_1
			$2p_1 - 2s$			
1,506·21*	66,392	1,316	$2p_1 - 3d_2$	$2p_1 = 169,078$	2·4169	6_2
1,476·94*	67,708		$- 3d_1$			
		14,805	$2p_2 - 3d_2$	$2p_2 = 183,883$	2·3175	6_2
2,531·63*	39,500	(45·5)	$3d_1 - 4f_2$	$3d_1 = 101,370$	3·1214	4_3
		1,270	$- 4f_1$			
2,452·76*	40,770		$3d_2 - 4f_2$	$3d_2 = 102,686$	3·1130	4_3
4,489·01	22,270·4	45·5	$4f_1 - 5g$	$4f_1 = 61,870$	3·9954	$5_4 (?)$
4,479·86	22,315·9		$4f_2 - 5g$	$4f_2 = 61,916$	3·9936	$5_4 (?)$
Assumed value $5g = 39,600$						5_5

* λ vac.

of measurement is, fortunately, good enough to allow of this being a fair test, since all the lines used are determined about $0\cdot02 \text{ \AA}$ (see Table XII); or at least they are consistent to this amount, even if the absolute values are in error. The identification of the $3d - 4f$ and $4f - 5g$ lines requires some defence, since the expected second member of the fundamental pair is not recorded, the strong line $\lambda 2452\cdot8$ being presumed a satellite. This is similar to the state of affairs in Ga III. No other arrangement has been found that was at all satisfactory, and bearing in mind that the separation of 1316 found for $3d_2 - 3d_1$ is correct to 1 unit, it is very strong confirmatory evidence to find $\delta\nu = 1270$. The separation of the $d - f$ pair is too small by 46 units, and the suggested $f - g$ pair are $45\cdot6$ units apart.

This latter pair occur in their expected region and are of the very diffuse character to be expected. The task of confirming these suggestions would be aided by the removal from the spectrum of lines due to Tl II, but it seemed inadvisable to delay while this necessarily somewhat lengthy task was attempted.

Tables I and VII show the satisfactory fit of the term values with the other spectra.

The f levels will be discussed further in § 6.

The d separation agrees with our proposed law $\delta\nu/C^2$ const. (see § 6).

The identification of the $2s-2p$ pair is doubtful. Only two pairs exist with $2s-2p_1$ in the region λ 1200—1400, with the correct separation, namely :—

	λ	ν	$\delta\nu$		m	$1/q$	
(1)	1323·76	75,542	14,807	$2s = 108,342$	3·6193	0·25121	A
(1)	1646·5	60,735					
(3)	1367·72	73,114	14,805	$2s = 110,769$	2·9860	0·24913	B
(3)	1715·0	58,309					

The second pair is preferable, as being stronger perhaps, but $1/q$ is not in accord with the $2s$ terms for Au I and Hg II for either (see fig. 3).

Germanium.—Electrodes were used, made of aluminium tubing packed with germanium oxide, made into a paste with dilute nitric acid and allowed to harden. One negative on a Schumann plate was obtained with the vacuum spectrograph covering the region between 600 Å and 1900 Å. The reduction was made by means of the known impurities present (*i.e.*, Al, C, N, O), and the few second-order lines present indicate that an accuracy of about 0·1 Å has been attained.

The Spectrum of Germanium IV.—The extrapolation from the $1s-2p_2$ lines of Cu I, Zn II, Ga III, to the corresponding pair in Ge IV, is quite definite and satisfactory. The pair found are very strong lines with the appropriate separation and fit closely to the linear law (Table II). The pair is shown in Plate 4. The agreement between the values

TABLE E.—The spectrum of Trebly-Ionised Germanium. Ge IV.

λ vac. I.Å.	ν	$\delta\nu$			m	n_k
1,189·0	84,104	2,790	$1s - 2p_1$	$1s = 368,701$	2·1822	4_1
1,229·8	81,314		$1s - 2p_2$			
847·8	117,952	2,794	$2p_2 - 2s$	$2s = 169,432$	3·2191	5_1
868·3	115,168		$2p_1 - 2s$			
938·9	106,508	250	$2p_1 - 3d_2$	$2p_1 = 284,598$	2·4838	4_2
36·7	758		$- 3d_1$			
915·0	109,290	2,782	$2p_2 - 3d_2$	$2p_2 = 287,386$	2·4717	4_2
1,500·6	66,640	254	$3d_1 - 4f$	$3d_1 = 177,840$	3·1421	4_3
1,494·9	66,894		$3d_2 - 4f$	$3d_2 = 178,094$	3·1398	4_3
Assumed value of $4f = 111,200$						4_4

of $2p_2 - 2p_1$ from the various pairs is within the limits of error. The $2p - 2s$ pair depends, for its identification, mainly on the value of the separation found and on a plausible value of $2s$ (see Table V, fig. 3). No satellite could be attached to the $3d - 4f$ pair with any plausibility.

The term values are based on an extrapolated value for $4f$ (see Table I, p. 378). It is worth pointing out that the $3d$ levels have become greater than the $2s$ level by the time this stage of ionisation has been reached in the sequence of copper-like atoms.

Tin.—Electrodes were used made of pure tin, and one plate was taken with the vacuum spectrograph covering the range, $\lambda\lambda$ 700—1900. Å.U.

Unfortunately, practically no standard lines are available to reduce the plate, and there are very few measures by other writers.

In order to obtain approximate wave-lengths for the purpose of identifying the principal doublet of Sn IV, a curve of corrections was obtained by using as standards the mean values of wave-lengths measured by Bloch,* and others tabulated by him. These wave-lengths so obtained are given in Table XIV at the end of this paper, and may be regarded as of about the same accuracy as the standards used, *i.e.*, probably subject to a smooth curve of corrections not exceeding 0.5°Å at any point.

The Spectrum of Sn IV.—In view of the uncertainty attaching to the wave-lengths, especially of $\lambda 1314.7$, not much could be done except to locate the principal pair. The

TABLE F.—The spectrum of Trebly-Ionised Tin. Sn IV.

λ vac. I.Å.	ν	$\delta\nu$			m	n_k
1,314.7	76,063	6,507	$1s - 2p_1$	$1s^* = 327,261$	2.3163	5_1
1,437.7	69,556		$1s - 2p_2$			
				$2p_1^* = 251,198$	2.6438	5_2
				$2p_2^* = 257,705$	2.6102	5_2

* Calculated values (*see* below).

term values have been obtained by extrapolation from the terms of Ag I — Cd II — In III. Values of $1/q$ for $1s$, $2p_1$, and $2p_2$ were estimated and the preliminary values $1s = 327,848$; $2p_1 = 251,070$; $2p_2 = 256,660$ obtained.

Adjusting the p terms to have the observed separation $\delta\nu = 6,507$, we get $2p_1 = 250,611$; $2p_2 = 257,118$, dividing the change equally. Then adjusting $1s - 2p_1$, and $1s - 2p_2$ to agree with the observed wave numbers we get

$$\begin{aligned} 1s &= 327,261, \\ 2p_1 &= 251,198, \\ 2p_2 &= 257,705. \end{aligned}$$

* BLOCH, 'Comptes Rendus,' vol. 177, p. 1025 (1923).

These values were placed in Table III and naturally give satisfactory values of $1/q$. The interesting point is that the values of $\sqrt{\nu(1s)} - \sqrt{\nu(2p)}$ are correct, so confirming our numbers (see Table VI).

The $p_2 - p_1$ separation yields a value of the screening constant well in accord with the sequence Ag I, etc., and the linear law of $1s - 2p$ is well borne out (see Table III).

Lead.—Electrodes of aluminium tubing containing a hardened paste of lead peroxide and dilute nitric acid were used. One plate was taken with the vacuum grating spectrograph, with a range of wave-lengths from λ 700 to λ 1950. Reduction of the measurements was effected with the aid of the usual standard lines and a general accuracy of 0.1 Å was reached. Comparison with the measures by LANG* shows general agreement, with, however, very different intensity ratios and a greater resolving power, as was remarked upon above under Thallium.

The Spectrum of Pb IV.—The Identification of the $1s - 2p$ pair is satisfactory, but extrapolation alone does not suffice to decide between the pair $\lambda\lambda$ 1029 and 1313, and the pair $\lambda\lambda$ 1049 and 1313. The reason for choosing the former instead of the latter pair is that the separation is satisfactory with either, though better with the pair chosen, and also no plausible pair and satellite for $2p - 3d$ could be found with $\lambda\lambda$ 1049 and 1313 as $1s - 2p$.

An appeal to the rule $\delta\nu/C^2 = \text{const.}$ for the d separations, however, excludes $\lambda\lambda$ 1049 and $\lambda\lambda$ 1313 as $1s - 2p$, since $2p - 3d$ is then 890.8, 1028.7, 1074.7 with $3d_2 - 3d_1 = 4150$, which is much too large. Taking, then, 1028.7 and 1313.2 as the principal pair we have

	A		B		C
(4)	883.9	(4)	890.8	(4)	922.5
(12)	1048.9	(4)	1069.2	(4)	1116.2
(3)	1085.69	(1)	1096.5	(3)	1145.0
$3d_2 - 3d_1 =$	3250		2329		2254

as possible $2p - 3d$ lines. $\Delta\nu$ is too large probably in A and the p 's become rather high. B seems the most plausible.

If we accept the doubling of the f levels in Tl III, then we expect a greater separation (say, 50–100 units) in Pb IV. Now in between the limits within which the $d-f$ lines can be expected, there is only one reasonably strong pair with anything near a probable separation, namely, $\lambda\lambda$ 1726.5 – 1796.6. This gives 2260, or 60 less than $(2p_1 - 3d_1) - (2p_1 - 3d_2)$, and the resulting arrangement agrees with Tl III in manner and in term values. Again, no $3d_1 - 4f_2$ line can be found.

The arrangement obtained by using C is tabulated below that for B. It is satisfactory on its own, but does not fit on to the Au I sequence so well, nor does it resemble

* LANG, *loc. cit.*

TABLE G.—The spectrum of Trebly-Ionised Lead. Pb IV.

λ vac. I.Å.	ν	$\delta\nu$			m	n_k
1,028·7	97,210	21,060	$1s - 2p_1$	$1s = 355,963$	2·2209	6_1
1,313·2	76,150		$1s - 2p_2$			
			$2p_2 - 2s$	$2s =$		7_1
			$2p_1 - 2s$			
1,096·5	91,199	2,329	$2p_1 - 3d_2$	$2p_1 = 258,752$	2·6049	6_2
69·2	93,528		$- 3d_1$			
890·8	112,259	21,060	$2p_2 - 3d_2$	$2p_2 = 279,812$	2·5050	6_2
(?)		2,260	$3d_1 - 4f_2$	$3d_1 = 165,217$	3·2599	4_3
1,796·6	55,661		$- 4f_1$	$3d_2 = 167,556$	3·2371	
1,726·5*	57,921		$3d_2 - 4f_2$			
			Assumed value $4f_1 = 109,566$ $4f_2 = 109,635$			5_4
1,145·0	87,336	2,254	$2p_1 - 3d_2$	$1s = 352,068$ $2p_1 = 254,854$		6_1 6_2
16·2	89,590		$- 3d_1$			
922·5	108,401	21,065	$2p_2 - 3d_2$	$2p_2 = 275,921$		6_2
1,796·6	55,661	2,260	$3d_1 - 4f$	$3d_1 = 165,261$		4_3
1,726·5*	57,921		$3d_2 - 4f$	$3d_2 = 167,521$		4_3
			Assumed value $4f = 109,600$			5_4

* See text, below.

Tl III in character. There is a line at $\lambda 1727\cdot5$ of the same intensity as $\lambda 1726\cdot5$, and there is no means of deciding, without vastly greater accuracy of wave-lengths, which of the two is the true companion to $\lambda 1796\cdot6$. I have indicated this in the table.

The identification of the $3d - 4f$ pair is doubtful, though the region is right, and the separation satisfactory, yet the lines are rather too easily excited under other circumstances, and it may be that $1796\cdot6$ and $1726\cdot5$ belong to Pb I or Pb II. It is probable that the members of these later series are not well developed in these spectra, and not much weight can be attached to their identification.

TABLE I.—Term Values. (ν/C^2).

1s	<i>Na I</i>	41,449	<i>Mg II</i>	30,317	<i>Al III</i>	25,495	<i>Si IV</i>	22,757·3
	<i>Cu I</i>	62,308	<i>Zn II</i>	36,223	<i>Ga III</i>	27,533	<i>Ge IV</i>	23,044
	<i>Ag I</i>	61,096	<i>Cd II</i>	34,094	<i>In III</i>	25,077	<i>Sn IV</i>	(20,454)
	<i>Au I</i>	74,510	<i>Hg II</i>	38,425	<i>Tl III</i>	27,561	<i>Pb IV</i>	22,248
2s	<i>Na I</i>	15,710	<i>Mg II</i>	12,866	<i>Al III</i>	11,477	<i>Si IV</i>	10,631·6
	<i>Cu I</i>	19,171	<i>Zn II</i>	14,114	<i>Ga III</i>	11,896	<i>Ge IV</i>	
	<i>Ag I</i>	18,540	<i>Cd II</i>	13,347	<i>In III</i>		<i>Sn IV</i>	
	<i>Au I</i>	19,928	<i>Hg II</i>	14,496	<i>Tl III</i>		<i>Po IV</i>	
2p ₁ 2p ₂	<i>Na I</i>	24,476	<i>Mg II</i>	21,377	<i>Al III</i>	19,504	<i>Si IV</i>	18,273·6
		24,493		21,399		19,530		18,302·3
	<i>Cu I</i>	31,524	<i>Zn II</i>	23,884	<i>Ga III</i>	20,103	<i>Ge IV</i>	17,787
		31,773		24,103		20,296		17,962
	<i>Ag I</i>	30,623	<i>Cd II</i>	22,440	<i>In III</i>	18,240	<i>Sn IV</i>	(15,700)
		31,543		23,060		18,723		(16,107)
	<i>Au I</i>	33,241	<i>Hg II</i>	23,273	<i>Tl III</i>	18,786	<i>Po IV</i>	16,172
		37,057		25,553		20,431		17,488
3d ₁ 3d ₂	<i>Na I</i>	12,276	<i>Mg II</i>	12,444·0	<i>Al III</i>	12,611·0	<i>Si IV</i>	12,731·6
				12,444·25		12,610·74		
	<i>Cu I</i>	12,366	<i>Zn II</i>	11,982·9	<i>Ga II</i>	11,512·1	<i>Ge IV</i>	11,115·0
		12,373		11,995·6		11,524·5		11,130·9
	<i>Ag I</i>	12,331	<i>Cd II</i>	11,632·8	<i>In III</i>	10,772·4	<i>Sn IV</i>	
		12,352		11,671·3		10,803·8		
	<i>Au I</i>	12,377	<i>Hg II</i>	12,038·5	<i>Tl III</i>	11,263·3	<i>Sb IV</i>	10,326·1
		12,457		12,179·3		11,409·6		10,472·3
4f ₁ 4f ₂	<i>Na I</i>	6,860	<i>Mg II</i>	6,867	<i>Al III</i>	6,871·28	<i>Si IV</i>	6,870·2
						6,871·33		
	<i>Cu I</i>	6,880	<i>Zn II</i>	6,907	<i>Ga III</i>	6,930·0	<i>Ge IV</i>	(6,950)
						6,930·7		
	<i>Ag I</i>	6,892	<i>Cd II</i>	6,985·6	<i>In III</i>	(7,080)	<i>Sn IV</i>	
			6,988·8					
	<i>Au I</i>		<i>Hg II</i>	(7,000)	<i>Tl III</i>	6,874·4	<i>Pb IV</i>	(6,847·9)
						6,879·6		(6,852·1)
5g	<i>Na I</i>		<i>Mg II</i>		<i>Al III</i>	4,392	<i>Si IV</i>	4,388·3
	<i>Cu I</i>		<i>Zn II</i>		<i>Ga III</i>	(4,395)	<i>Ge IV</i>	
	<i>Ag I</i>		<i>Cd II</i>		<i>In III</i>		<i>Sn IV</i>	
			<i>Hg II</i>		<i>Tl III</i>	(4,400)	<i>Pb IV</i>	
	<i>Au I</i>							

Assumed or calculated values are enclosed in brackets ().

§ 6. Discussion of the Results Obtained.

It must be remembered in considering these results that though each proposed series arrangement has been justified, to a greater or less extent, on its own merits, yet the falling of the whole into a coherent scheme is of prime importance in establishing the classification. It is true that there is some independent evidence, *e.g.*, the experiments of TURNER and COMPTON on Hg II, and we also know the behaviour of the sequence of atoms like lithium and sodium to be similar to those we are considering, but since various laws have been used, as explained in § 4, in searching for the series spectra,

it cannot be claimed, without argument in a circle, that the results show of themselves the various laws of progression. Nevertheless, it is of interest to examine the data as a whole at this point, taking the correctness of the classifications for granted, if only for the sake of making quite clear exactly what has been done.

We have, then, a scheme of spectra, of atoms homologous with copper, with silver, and with gold and extending to the third stage of ionisation. Of these spectra, five (Cu I, Ag I, Au I, Zn II, Cd II) have been established by previous workers quite independently of the considerations advanced in this paper. The remainder (Hg II, Ga III, In III, Tl III, Ge II, Sn IV, Pb IV) have been based upon considerations set forth in § 4, which depend upon the results obtained by A. FOWLER, PASCHEN, MILLIKAN and BOWEN, LANDÉ and HARTREE, in their work on the spectra of the sequence of ionised atoms like lithium and sodium, and their interpretation in terms of BOHR'S theory of spectra. The methods used in the present paper have been, on the whole, those due to MILLIKAN and BOWEN, but we shall now examine the sequence of spectra in the light of various relationships found to hold for the lighter elements.

(6.1.) *The Progression of the Principal Doublets.*

The pair of lines $1s - 2p_1$ and $1s - 2p_2$ are the most easily and the most certainly detectable lines in the spectrum. They are indicated in the various spectra in Plate 4. The wave numbers of these lines for the whole sequence are tabulated in Table II,

TABLE II.—The progression of the principal doublets. $1s - 2p_{1, 2}$.

$n_k - n_{k'}$	Z	$1s - 2p_2$	Difference.	$1s - 2p_1$	Difference.
$4_1 - 4_2$	29 Cu I	30,535		30,784	
	30 Zn II	48,483	17,948	49,355	18,571
	31 Ga III	65,161	16,678	66,874	17,519
	32 Ge IV	81,314	16,153	84,104	17,230
$5_1 - 5_2$	47 Ag I	29,552		30,473	
	48 Cd II	44,136	14,584	46,619	16,146
	49 In III	57,182	13,046	61,527	14,908
	50 Sn IV	69,556	12,374	76,063	14,536
$6_1 - 6_2$	79 Au I	37,359		41,174	
	80 Hg II	51,485	14,126	60,612	19,438
	81 Tl III	64,160	12,675	78,968	18,356
	82 Pb IV	76,150	11,990	97,210	18,242

together with the first differences. We saw in § 4 that it is to be expected that there should be a linear variation of the wave number with Z , the atomic number, and this is very well borne out. In fig. 1 the results have been shown graphically. The progression

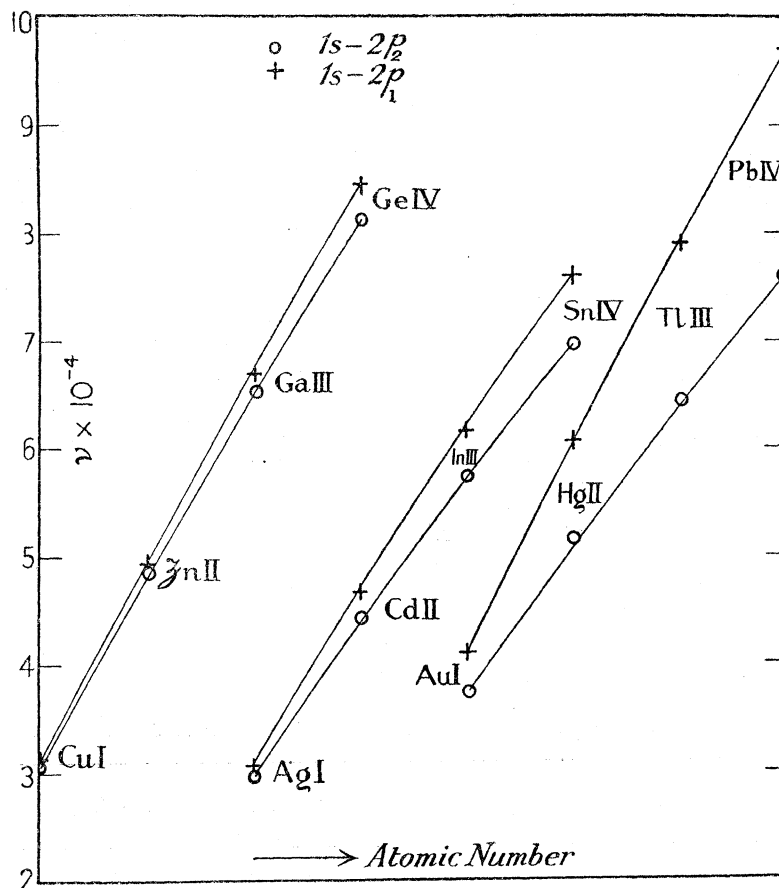


FIG. 1.—The progression of the lines of the principal doublets.

is not exactly linear, but the departure from the simple law seems to be decreasing with increasing ionisation. This is just what is observed in the spectra of the lighter elements. It may seem somewhat surprising that both $1s - 2p_2$ and $1s - 2p_1$ show a nearly linear progression, since if $1s - 2p_2 = \alpha Z + \beta$ and (as we shall see presently) $2p_2 - 2p_1 = \gamma (Z - s)^4$, we have $1s - 2p_1 = \alpha Z + \beta + \gamma (Z - s)^4$. Sooner or later, Z^4 must become the leading member, and the departure from linearity will then become large. The reason this feature does not appear is twofold. First, γ is very small and α is large, and, secondly, s is not constant; $\delta s / \delta z$ may be greater than unity at first, becoming less as the atomic number Z increases. Thus:—

$$\frac{\partial \nu}{\partial z} = \frac{\partial (1s - 2p_1)}{\partial z} = \alpha + 4\gamma (Z - s)^3 \left\{ 1 - \frac{\partial s}{\partial z} \right\}.$$

For the sequence Cu I — Zn II ... , taking average values over our range $\alpha =$ about 14,900; $\gamma = 0.0456$; $Z - s = 12$; $\delta s / \delta z = 1.5$ say.

Thus the second member on the right-hand side of our equation is small (*i.e.*, < 200) compared with the first term ($\alpha = 16,500$), and will not become appreciable till, at any rate, after the fourth stage of ionisation.

These calculations are exceedingly rough, but there is no point in attempting to make them accurate, since we are only concerned to show that an apparent anomaly need not cause us concern.

(6.2.) *The Principal Doublet Separations* ($2p_2 - 2p_1$).

In § 4 it was pointed out that either the law for the X-ray doublets, due to SOMMERFELD ($\Delta\nu = \xi \left(\frac{Z-s}{n}\right)^4$), or the modification of it for optical spectra, due to LANDÉ ($\Delta\nu = \frac{\alpha C^2 R (Z-s)^2}{n_a^3 k (k-1)}$)* might be used to represent the variation of doublet separation in these spectra. This second formula admits of a somewhat simpler statement. The complete expression, which uses the whole series of terms of the SOMMERFELD relativity correction, is

$$\begin{aligned} \Delta\nu &= \frac{R\alpha^2 C^2 (Z-s)^2}{n_a^3 k (k-1)} \left\{ 1 + \frac{5}{8}\alpha^2 (Z-s)^2 + \frac{5}{8} \frac{\alpha^4}{2^4} (Z-s)^4 + \dots \right\} \\ &= \frac{2R\alpha^2 C^2 (Z-s)^2}{n_a^3 k (k-1)} \gamma \dots \dots \dots (5A) \end{aligned}$$

where 2γ represents the sum of the series in brackets. Now also we have

$$\nu = \frac{C^2 R}{(n-q)^2} = \frac{C^2 R}{n_a^2},$$

therefore

$$\Delta\nu = \frac{2C^2 R}{(n-q)^3} \Delta q.$$

Thus

$$\Delta q = \frac{(Z-s)^2}{k(k-1)} \alpha^2 \gamma \dots \dots \dots (6)$$

Thus

$$\sqrt{\Delta q/\gamma} \text{ should be linear in } Z. \dots \dots \dots (7)$$

Now, since for the p orbits $k = 2$,

$$\Delta q (p) = \frac{1}{2} (Z-s)^2 \alpha^2 \gamma,$$

* The s in LANDÉ'S formula is not the same as the s in SOMMERFELD'S formula. The latter is given in Table III, the former (LANDÉ s) is omitted to avoid confusion; its value depends upon the term values chosen and varies between 1.5 and 5, and can be found from the relation

$$(Z-s) = \frac{1}{0.00364} \times \sqrt{\frac{\Delta q}{2\gamma}}.$$

and when $2\gamma = 1$ very nearly,* an approximate value is

$$2\gamma = 1 + \frac{5}{2} \Delta q (p) + \frac{53}{8} \Delta q (p)^2 + \dots$$

Now MILLIKAN and BOWEN use SOMMERFELD'S formula, and the present writer has done the same from motives of convenience, as explained in § 4. We shall, then, discuss the data in the light of the X-ray doublet formula, despite the theoretical preference for formula (7). Afterwards we will return to the discussion of the latter formula.

TABLE III.—The progression of the principal doublet separations.

Z	n_k	$2p_2 - 2p_1$ = Δv	$(\Delta v)^{\frac{1}{2}}$	$\frac{\Delta v = \beta (Z-s)^4}{\beta^* \times 10^2 Z-s}$	s	Diff.	$\sqrt{\frac{\Delta q}{2\gamma}}$
29 Cu I	4_2	248	3.969	8.59	20.41	2.17	0.0850
30 Zn II		873	5.436	11.76	18.24	1.16	0.0972
31 Ga III		1,715	6.435	13.92	17.08	0.81	0.1039
32 Ge IV		2,790	7.268	15.73	16.27		0.1081
47 Ag I	5_2	921	5.509	14.09	32.91	2.96	0.1612
48 Cd II		2,483	7.059	18.05	29.95	1.70	0.1685
49 In III		4,342	8.117	20.75	28.25	1.21	0.1717
50 Sn IV		6,507	8.981	22.96	27.04		0.1760
79 Au I	6_2	3,815	7.859	23.06	55.94	4.61	0.2780
80 Hg II		9,123	9.773	28.67	51.33	2.69	0.2817
81 Tl III		14,807	11.031	32.36	48.64	1.98	0.2817
82 Pb IV		21,060	12.047	35.34	46.66		0.2823

* β is related to the relativity constant α of SOMMERFELD by $\beta = \left(\frac{n_r}{n_a} - \frac{n_r'}{n_a'}\right) \frac{R\alpha^2}{n^4}$.

The LANDÉ formula 5 or 6 does not fit the results without some adjustment of s , and it is difficult to apply until the spectra are completely worked out, since the constants involved cannot be found independently. We need much more for our purpose a simple extrapolation formula, and the rule $\Delta v = \xi \frac{(Z-s)^4}{n}$ supplies our need very well. ξ is

* For Au I, Ag I, etc., $2\gamma =$ about 1.25 and the more accurate approximation

$$2\gamma = 1 + \frac{5}{2} \left(\frac{\Delta q}{2\gamma}\right) + \frac{53}{8} \left(\frac{\Delta q}{2\gamma}\right)^2 + \frac{303}{16} \left(\frac{\Delta q}{2\gamma}\right)^3$$

was used.

calculable and n is known, so that the extrapolation of values of s depends only on whether the curve obtained by plotting $Z - s$ against $n (\Delta \nu / \xi)^{\frac{1}{4}}$ is suitable.

In Table III are given the numerical results of applying this formula, and in fig. 2

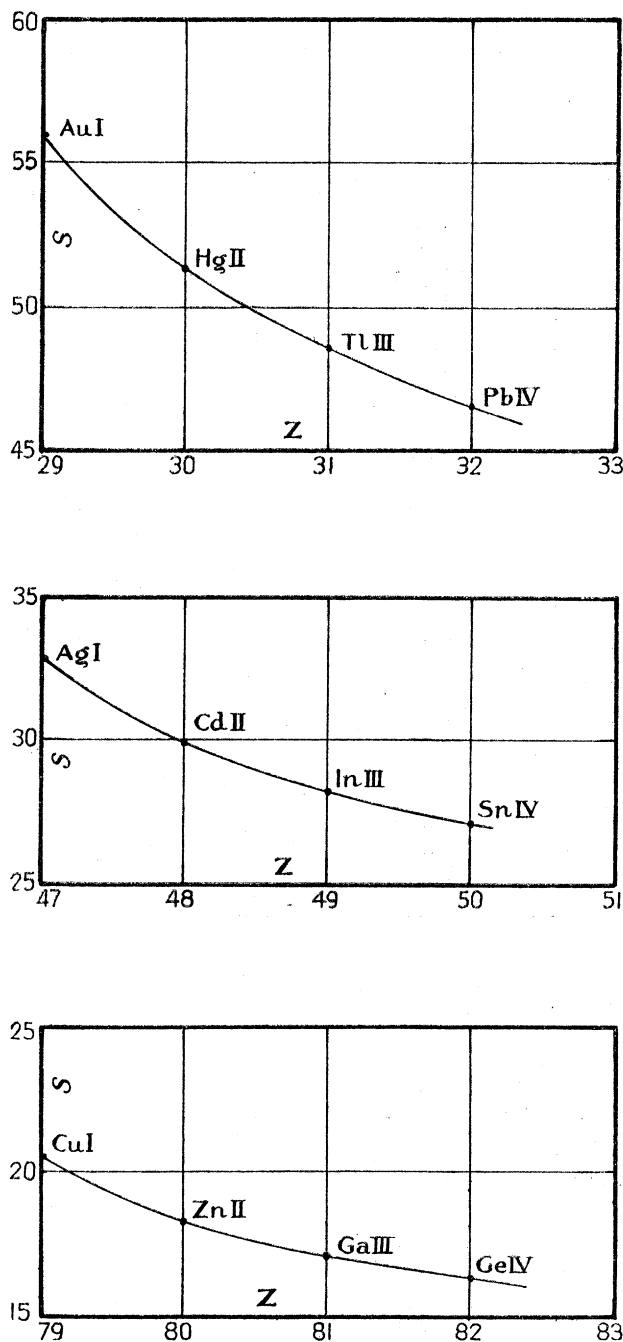


FIG. 2.—The progression of the principal doublet separations.

they are illustrated graphically. It will be seen that the curves are very smooth, progress uniformly from one sequence to another, and are eminently suitable for our purpose.

From our present point of view, then, they can be said to justify the classifications very well.

The result of applying the LANDÉ rule in the form (7) are tabulated in Table III.

The aim of the present paper is to present certain results rather than to discuss their theoretical significance, so that no further comment will be made here other than to remark that, while formula (4) was used in finding the series spectra, an appeal to formula (7) for justification seems to the writer to be more satisfactory.

TABLE IV.—The diffuse doublets $3d_2-3d_1$.

Z	n_k	$\left. \begin{matrix} 3d_1 \\ 3d_2 \end{matrix} \right\} \nu/C^2$	Diff.		$\Delta\nu$	$\Delta\nu/C^2$
29 Cu I	3_3	12,366			6·9	6·9
		12,373	383			
30 Zn II	4_3	11,982·9		377	51	12·8
		11,995·6	471			
31 Ga III	4_3	11,512·1		471	112	12·4
		11,524·5	397			
32 Ge IV	4_3	11,115·0		395	252	15·8
		11,130·9				
47 Ag I	3_3	12,331			20·3	20·3
		12,352	698			
48 Cd II	4_3	11,632·8		681	154	38·5
		11,671·3	861			
49 In III	4_3	10,772·4		867	283	31·4
		10,803·8				
50 Sn IV	4_3					
79 Au I	3_3	12,377			82·4	82·4
		12,457	338			
80 Hg II	4_3	12,038·5		278	563	140·8
		12,179·3	776			
81 Tl III	4_3	11,263·3		769	1,316	146·2
		11,409·6	937			
82 Pb IV	4_3	10,326·1		928	2,329	145·6
		10,472·3				

NOTE.—The small discrepancies between columns 3 and 6 are due to the fact that column 6 is derived from the measured values of the d separations averaged directly, while the term values ν/C^2 in column 3 are derived from terms obtained by distributing the errors of measurement somewhat differently.

(6.3.) *The Diffuse Term Separations.*

Let us now examine the $d_2 - d_1$ separations which are given in Table IV.

In the last column is printed $\Delta\nu/C^2$ for $d_2 - d_1$. The remarkable fact is evident that $\Delta\nu/C^2$ is constant for a given sequence, while n remains unchanged. The peculiar nature of the d terms will be dealt with below (§ 6.4). It seems that for the arc spectra the $3d$ term corresponds to a 3_3 orbit, but in the remaining spectra they are 4_3 . The

zero. First of all we expect, following HARTREE, that the values of $1/q$ should be linear in Z . The tables show that this is a very well-obeyed rule, and fig. 3 (below) illustrates

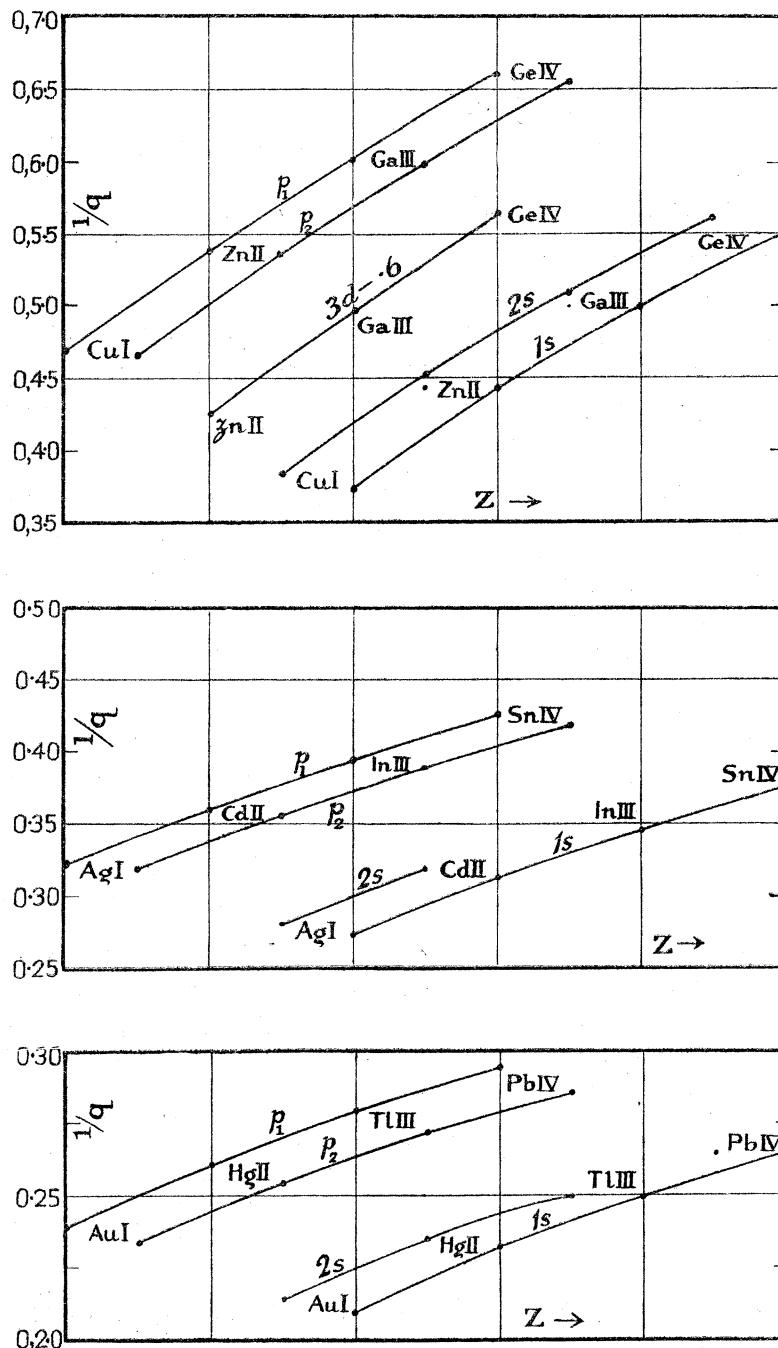


FIG. 3.

graphically the results. The departure from a linear law decreases with increasing ionisation, and there is a regular change of the slopes of the curves as we pass from the Cu I sequence to the Au I sequence. Not very many $2s$ levels are found, but it is

TABLE V.—Term values, etc., in the sequence Cu I—Zn II—Ga III—Ge IV.

	n_k	$\nu = \frac{C^2R}{m^2}$	$m = (n-q)$	q	$1/q$	$\sqrt{\nu}$	$\sqrt{\nu}(1s)$ $-\sqrt{\nu}(2p)$
1s	Cu I Zn II Ga III Ge IV	62,308 ¹	1.3271	2.6729	0.37413	249.62	
		144,890 ²	1.7406	2.2594	0.44260	380.64	
		247,797	1.9964	2.0036	0.49910	497.79	
		368,701	2.1822	1.8178	0.55012	607.21	
2s	Cu I Zn II Ga III Ge IV	19,171 ¹	2.3921	2.6079	0.38345		
		56,454 ²	2.7884	2.2116	0.45216		
		107,064	3.0374	1.9626	0.50953		
		169,432	3.2191	1.7809	0.56151		
2p ₁ 2p ₂	Cu I Zn II Ga III Ge IV	31,524 ¹	1.8658	2.1342	0.46856	177.55	72.1
		31,773 ¹	1.8584	2.1416	0.46694	178.25	71.4
		95,537 ²	2.1435	1.8565	0.53865	309.09	71.6
		96,410 ²	2.1338	1.8662	0.53585	310.50	70.1
3d ₁ 3d ₂	Cu I Zn II Ga III Ge IV	180,923	2.3364	1.6636	0.60111	425.35	72.4
		182,636	2.3254	1.6746	0.59716	427.36	70.4
		284,598	2.4838	1.5162	0.65954	533.48	73.7
		287,386	2.4717	1.5283	0.65432	536.06	71.1
3d ₁ 3d ₂	Cu I Zn II Ga III Ge IV	12,366 ¹	2.9789	0.0211			
		12,373 ¹	2.9781	0.0219			
		47,931 ²	3.0248	0.9752	1.0254		
		47,982 ²	3.0246	0.9754	1.0252		
4f	Cu I Zn II Ga III Ge IV	103,609	3.0874	0.9126	1.0958		
		103,721	3.0858	0.9142	1.0939		
		177,840	3.1421	0.8579	1.1656		
		178,094	3.1398	0.8602	1.1625		
5g	Cu I Zn II Ga III Ge IV	6,880 ¹	3.9938	0.0062			
		27,628 ²	3.8595	0.1405			
		62,370	3.9793	0.0207			
		62,376	3.9791	0.0209			
		(111,200) ³	3.9736	0.0264			
		(39,555) ³	4.9969	0.0031			
				R = 109,737.0			

¹ A. Fowler. 'Report on Series in Line Spectra' (1922).² G. v. Salis. 'Ann. der Physik,' vol. 76, p. 145.³ Assumed or calculated values are enclosed in brackets ().

worth noting that the change with atomic number (*i.e.*, increasing ionisation) in any one sequence brings the value of 2s below that of the *d* level by about the third stage of ionisation. Another relationship we expect to be fulfilled is due to the fact that the 1s — 2p₂ line shows a linear progression with *Z*. This we saw in § 4 involves the law

$$\sqrt{\nu(1s)} - \sqrt{\nu(2p)} = \text{constant.}$$

The two tests of our scheme are not quite equivalent, for in one test we use only

TABLE VI.—Term values, etc., in the sequence Ag I—Cd II—In III—Sn IV.

	n_k	ν	$m = n - q$	q	$1/q$	$\sqrt{\nu}$	$\sqrt{\nu}(1s) - \sqrt{\nu}(2p)$
$1s$	5 ₁	Ag I	61,096 ¹	1·3402	3·6598	0·27324	247·18
		Cd II	136,377 ²	1·7941	3·2059	0·31192	369·29
		In III	225,690	2·0919	2·9081	0·34387	475·07
		Sn IV	(327,261) ³	2·3163	2·6837	0·37262	572·07
$2s$	6 ₁	Ag I	18,540 ¹	2·4329	3·5671	0·28034	
		Cd II	53,386 ²	2·8674	3·1326	0·31922	
		In III					
		Sn IV					
$2p_1$ $2p_2$	5 ₂	Ag I	30,623 ¹	1·8930	3·1070	0·32185	174·99
		Cd II	31,543 ¹	1·8652	3·1348	0·31900	177·60
		In III	89,758 ²	2·2114	2·7886	0·35860	299·60
		Sn IV	92,241 ²	2·1809	2·8191	0·35472	303·71
$3d_1$ $3d_2$	4 ₃	Ag I	164,164	2·4528	2·5472	0·39259	405·17
		Cd II	168,506	2·4210	2·5790	0·38775	410·49
		In III	(251,198) ³	2·6438	2·3562	0·42441	501·20
		Sn IV	(257,705) ³	2·6102	2·3898	0·41845	507·65
$4f_1$ $4f_2$	4 ₄	Ag I	12,331 ¹	2·9831	0·0169		
		Cd II	12,352 ¹	2·9806	0·0194		
		In III	46,531 ²	3·0714	0·9286	1·0769	
		Sn IV	46,685 ²	3·0663	0·9337	1·0710	
$4f_1$ $4f_2$	4 ₄	Ag I	96,952	3·1917	0·8083	1·2372	
		Cd II	97,234	3·1871	0·8129	1·2302	
		In III					
		Sn IV					
			R = 109,737·0.				

¹ A. Fowler. 'Report on Series in Line Spectra' (1922).² G. v. Salis. 'Ann. der Physik,' vol. 76, p. 145.³ Assumed or calculated values are enclosed in brackets ().

measures of wave-length, and in this second one we use term values depending on the correctness of the whole series classification. The values of $\sqrt{1s} - \sqrt{2p}$ shown in Tables V, VI and VII turn out to be very nearly constant in any one sequence. According to equations 2 and 3, of § 4, there is a relation between the slope of the lines in fig. 1 and the constant $\sqrt{1s} - \sqrt{2p_2}$.

Thus

$$\frac{\partial}{\partial Z} (1s - 2p_2) = \frac{2R^{-\frac{1}{2}}}{n} (\sqrt{1s} - \sqrt{2p_2}).$$

This relation is not found to be exact, but is approximately true; thus, in the sequence

TABLE VII.—Term values, etc., in the sequence Au I—Hg II—Tl III—Pb IV.

	n_k	ν	$m = n - q$	q	$1/q$	$\sqrt{\nu}$	$\sqrt{\nu}(1s) - \sqrt{\nu}(2p)$
1s	6 ₁	Au I	74,510 ¹	1·2136	4·7864	0·20893	272·97
		Hg II	153,701	1·6899	4·3101	0·23201	392·05
		Tl III	248,045	1·9954	4·0046	0·24971	498·04
		Pb IV	355,963	2·2209	3·7791	0·26461	596·63
2s	7 ₁	Au I	19,928 ¹	2·3466	4·6534	0·21490	
		Hg II	57,984	2·7514	4·2486	0·23537	
		Tl III					
		Pb IV					
2p ₁ 2p ₂	6 ₂	Au I	33,241 ¹	1·8169	4·1831	0·23906	182·32
			37,057 ¹	1·7208	4·2792	0·23369	192·50
		Hg II	93,090	2·1715	3·8285	0·26120	305·11
			102,210	2·0723	3·9277	0·25460	319·70
		Tl III	169,078	2·4169	3·5831	0·27909	411·19
	183,883	2·3175	3·6825	0·27155	428·82		
	258,752	2·6049	3·3951	0·29454	508·68		
	279,812	2·5050	3·4950	0·28612	528·97		
3d ₁ 3d ₂	3 ₃	Au I	123,77 ¹	2·9776	0·0224		
			12,457 ¹	2·9680	0·0320		
	Hg II	48,154	3·0192	0·9808	1·0196		
		48,717	3·0017	0·9983	1·0017		
	4 ₃	Tl III	101,370	3·1214	0·8786	1·1382	
			102,686	3·1130	0·8870	1·1274	
	4 ₃	Pb IV	165,217	3·2599	0·7401	1·3512	
			167,556	3·2371	0·7629	1·3108	
4f ₁ 4f ₂	4 ₄	Hg II	(28,000) ²	3·9594			
		Tl III	61,870	3·9954			
			61,916	3·9936			
	Pb IV	5 ₄ (?)	(109,566) ²	4·003			
			(109,635) ²	4·002			
5g	Tl III	5 ₅	(39,600) ²	4·9940			

$$R = 109,737\cdot0$$

¹ V. THORSEN. 'Die Naturwissenschaften,' vol. 25, p. 500 (1923).

² Assumed or calculated values are enclosed in brackets ().

Cu I, etc., we have $\frac{\partial}{\partial Z}(1s - 2p_2) = 16,900$ $n = 4$ —whence the calculated value of $\sqrt{1s} - \sqrt{2p_2} = 102$. The observed value is 73.

No reasonable change in the value of R will bring these quantities into better agreement, nor can any alteration in n be countenanced. It is true that changing n from 4 to 3 will make the calculated constant $\sqrt{1s} - \sqrt{2p} 76$, but this would upset the doublet separation relations and the variation of $1/q$ with Z . The point is not worth stressing since the formulæ are only approximate, and $1s - 2p_2$ departs from a linear law far enough to account for the discrepancy. It is quite sufficient to see that the orders of the

quantities agree. The important fact is that $\sqrt{1s} - \sqrt{2p}$ is as constant as it turns out to be.

The discrepancy in the sequence Au I, etc., is of the same order; thus, $\sqrt{1s} - \sqrt{2p_2} = 87$, and the calculated value is 117. No change of n will here bring the results into coincidence so that the effect of changing n in the Cu I sequence is probably accidental.

(ii) *The outer levels.*—When g levels can be used, it is found that the resulting f terms are hydrogenic in magnitude. This justifies our method of calculating the terms by assigning to the g level a value nearly corresponding to a hydrogen orbit of the same quantum numbers in a simple Coulomb field (with the central charge of appropriate magnitude). The d levels are of interest, inasmuch as the quantum defect is very small, and would change sign as the ionisation increases, if $n_k = 3_3$ were retained throughout.

At first the defect is positive, and this agrees with the assignment of the d level to a 3_3 orbit. Mr. HARTREE has pointed out to me that the change from a positive to a negative value of the quantum defect indicates that the d orbit becomes of the more eccentric type 4_3 . We can gain some idea of the mechanism involved by considering an atom model consisting of a core and series electron. In the first stages (no ionisation) the electron occupying a 3_3 orbit pursues a path probably quite outside the core. When the nuclear charge is increased, which is the effect of ionisation, the core will be somewhat contracted, but the effect of the change on the valence electron will be more marked, the 3_3 orbit may cease to be a possible one and the 4_3 orbit would then be the lowest available d level (see also fig. 3, top section).

In Table I it will be seen that, while the progression of f terms along a sequence is quite regular, there is an abrupt change when we come to Tl III in the direction of the progression. Till that point, the term value increases, both with atomic number (down) and with increasing ionisation (across).

With thallium there is a sudden decrease in f , which cannot be removed by any reasonable change in g . It might be that the $4f$ orbit has become 5_4 instead of 4_4 , but $4f$ for Tl III is scarcely low enough to justify this hypothesis.

(6.5.) *The Quantum Numbers.*

Some remarks upon the quantum numbers assigned to the orbits have been made in § 6.4. The numeration adopted follows the scheme of BOHR deduced from X-ray and optical data. The various relations between the term values and lines are found to be best represented by the use of these numbers, and any change will seriously impair most of them. The scheme of quantum numbers proposed by TURNER* is definitely not applicable since no adjustment of the whole quantum number by integral amounts will make the values of the quantum defects lie on a straight line for any one level throughout a sequence of the type Cu I—Ag I—Au I. That is to say, that for the $1s$ level, for instance, a relation

$$q = aZ + b$$

cannot be found by altering n by any integers, such as would fit his diagrams.

* L. A. TURNER, 'Phil. Mag.', vol. 48 (1924).

There is an anomaly to be noted in the treatment of the azimuthal quantum numbers of the p orbits. In § 4 we mentioned this difficulty in deriving the formulæ for the doublet separations. In calculating the $1s - 2p_2$ separation we take both the orbits to be n_2 , but in calculating the $p_2 - p_1$ separation we take one orbit to have an azimuthal quantum number $k = 1$ and the other $k = 2$. This difficulty occurs in the lighter elements, and has been discussed by MILLIKAN and BOWEN, by LANDÉ, and by BOHR, and need not detain us further than to remark that the most acceptable statement at the present seems to be that there is a species of twofoldness in the atom, that allows an orbit to possess different quantum numbers in different transition processes.

(6.6.) *Notation.*

In this paper, lines have been denoted by numbering the levels in their order in the atom thus:—

The first s level is $1s$		
,,	p	,, $2p$
,,	d	,, $3d$
,,	f	,, $4f$
,,	g	,, $5g$

There is admittedly a certain element of arbitrariness in this procedure, and it is less objectionable from a theoretical point of view to use the true whole quantum numbers. Thus $1s$ in Cu I would then be $4s$. The reason for my adoption of the notation used is that it enables corresponding lines in different spectra to be identified more readily than does the other scheme. Thus, in this paper, $1s - 2p_2$ denotes a transition between the lowest state in the atom and the lowest p level (*i.e.*, a resonance line), whereas in the other scheme this line is denoted by $4s - 4p_2$ for Cu I, etc., by $5s - 5p_2$ for Ag I, etc., by $6s - 6p_2$ for Au I, etc.

(6.7.) *The Series Scheme.*

It appears from what has been demonstrated above that a consistent scheme of series spectra has been developed, and that the tests available confirm the arrangements. The correctness of the identifications of series lines is not, however, so certain in general as it is in ordinary arc spectra, since the necessary tests are not possible. Consequently, while it is believed that the results are correct, it is not shown that the conditions to be fulfilled have specified a unique arrangement. The probability of a pair of lines falling accidentally in the place where series lines are to be expected exists, but the possibility of a wrong identification is very much diminished by correlating all the spectra in the manner described and by confining attention to the stronger lines. The principal doublets are scarcely open to doubt, and the diffuse doublets and satellites are in almost as strong a position. The $2p - 2s$ lines are usually weak, and lie in a portion of the spectrum not very accurately measurable, but it was rarely that any alternative pairs were found, and in those spectra where no definite choice between pairs of lines complying

equally well with the tests available could be made, no lines have been placed in the tables, or the fact has been indicated.

The fundamental lines seem satisfactory on the whole; they are strong lines and not difficult to pick out. There is some uncertainty about the satellites, but the $4f-5g$ pair when it can be found strengthens the identification made. These points are entered into in § 5 as they arise in considering each spectrum. It is only necessary to point out here that the methods employed are not capable of yielding definite proof of the identity of lines, but make the identifications adopted probable to the degree I have indicated.

§ 7. In conclusion, I gladly take this opportunity of making acknowledgments to those whose courtesy and assistance have made this work possible. In the first place, my thanks are due to Prof. R. A. MILLIKAN for his kindness in allowing me the freedom of his new vacuum spectrograph in his laboratory at Pasadeña, and for much information and instruction in this subject. To Mr. I. S. BOWEN, of the California Institute of Technology, I am also under a great debt for his personal guidance in the technique of work with the vacuum spectroscope and in the interpretation of the spectra so obtained.

The Director of the Mt. Wilson Observatory kindly allowed me the use of facilities in the laboratory at Pasadeña, where Dr. ANDERSON was very helpful in giving me the use of his condenser and spectrograph to obtain some of my plates, and of his measuring machine for their reduction. Finally, my thanks are due to Mr. D. R. HARTREE, of St. John's College, Cambridge, for his helpful criticism and calculations of approximate term values, and to Prof. H. F. NEWALL, who urged me to complete at the Cambridge Solar Physics Observatory the investigations begun in Pasadeña.

§ 8. *Summary of New Results.*

From spectra of the spark *in vacuo* photographed by the author, a scheme of series classifications has been developed. The doublet spectra of Hg II, Ga III, In III, Tl III, Ge IV, Sn IV, Pb IV have been arranged in series groups by the aid of experimental and theoretical investigations by previous writers on the spectra of atoms like lithium and sodium. The various numerical relations between the spectra have been investigated and the results are tabulated and illustrated in curves. It is found that the theoretical results of SOMMERFELD, LANDÉ and HARTREE are well borne out. A new rule of the variation of diffused doublet separations with ionisation is proposed.

The vacuum-spark spectra are very rich in lines, and a full table of wave-lengths is appended. Efforts have been made to improve the accuracy of measurement and reduction to wave-lengths, and special success has been attained for thallium where a series of lines between 1000 Å and 5500 Å have been obtained with an accuracy of a few hundredths of an Ångström unit. These may be of service in future work in the far ultra-violet.

Notes on the Tables of Wave-Lengths.

The methods of measurement and reduction have been described in § 3. A few numerical details may be added here. The measuring machines used were read to 0.001 mm., the scale being about 16.7 Å.U. per mm. It was found that with lines of average quality the settings were repeatable to about 0.005 mm., so that the error might be 0.1 Å. Many lines were better than this, but, except there be some additional independent measures, twice this is taken as the error of measurement. It was found that the lines used in forming the correction curves lay quite close to the final curve and only rarely were more than 0.2 Å away. See also § 3, p. 359, last two paragraphs.

[*Note added December 7, 1925.*—The Al group at λ 1763 affords an opportunity to test the accuracy of measurement, since the correction curve can only be in error, over the range covered by these five lines, by a small constant amount. Thus the variation of the quantity (measured λ —standard λ) may be taken as giving the accuracy of measurement.

Using as standards the means of the values in Table VIII (i) and (ii) we get for this group:

	Ga (A).	Ga (B).	In.	Pb.
Greatest error of a single measurement in first order ...	0.03	0.03	0.03	0.03
Mean error	0.017	0.024	0.017	0.012

Thus on a well-defined line the error due to inaccuracies of *measuring* should not exceed 0.05 Å.U., and, making an allowance for the correction curve being in error by twice this amount in regions where there are no standard lines close by, we should have as the possible error in the wave-length a quantity ≤ 0.15 Å.U.]

Very strong, diffuse, or very faint lines are liable to larger errors. In forming the mean values of the wave-lengths from independent measures, or from several orders, weights have been assigned proportional to the order of the line's occurrence, unless there has been some special reason for doing otherwise (*e.g.*, a fault in the plate, or an imperfectly focussed image).

The preliminary wave-lengths were worked out to 0.01 Å and the correction curve could be read to 0.01 Å; if only one measure of a line was available it is given corrected to the nearest tenth of an Å.U., otherwise both figures are retained.

Some caution is needed in identifying lines as being 2nd, or higher, order positions of lines of short wave-length, and intensities are taken into consideration as well as numerical coincidence.

Suspected impurities have been indicated, most of the lines identified as due to impurities are certainly so, but none are suppressed to avoid danger of eliminating a line not an impurity which may have nearly the same wave-length as one that is.

Explanation of the signs used in the tables.

$0^1 0^2$, etc.	...	...	Denote measures of a line in the 1st, 2nd, etc., orders.
Al, O, C	...	...	Denote the element to which a line (supposed an impurity) is due.
(977.02)	...	...	Figures in brackets denote the standard wave-length of a line as given in Table I.
p.	...	...	Poor measure due, <i>e.g.</i> , to a fault in the plate.
d.	...	...	Double.
δ	...	...	Diffuse.
?	...	...	Doubtful existence.
A, B	...	...	Denote measures on different plates.

TABLE VIII.

(i) *Standard Wave-Lengths*

(from measures by BOWEN).

The intensities represent very roughly the strength of the lines when they appear as "impurities" in the vacuum spark spectra photographed by MILLIKAN'S method.

<i>Carbon.</i>		<i>Oxygen.</i>		<i>Nitrogen.</i>		<i>Aluminium.</i>	
Int.	λ vac. I. Å.	Int.	λ vac. I. Å.	Int.	λ vac. I. Å.	Int.	λ Int. I. Å.
1	687·10	1	507·45	1	685·04	5	1384·16
1	687·39	1	507·75	1	685·55	8	1605·83
1	858·09	1	508·23	1	685·86	8	1611·93
1	858·55	1	525·82	1	686·39	6	1719·50
1	903·63	1	553·33	1	763·37	7	1721·28
2	903·98	1	554·07	1	764·39	8	1725·01
2	904·17	1	554·52	1	765·21	4	1760·12
1	904·48	1	555·23	1	771·59	4	1761·96
2	977·02	2	599·60	1	771·97	5	1763·95
1	1009·86	1	608·41	1	772·45	4	1765·81
1	1010·10	1	609·85	1	772·97	4	1767·75
2	1010·38	1	610·06	1	915·71		
2	1036·35	1	610·79	1	916·13		
2	1037·03	1	616·33	2	916·82		
1	1174·97	1	617·05	2	989·90		
1	1175·31	1	624·61	3	991·66		
2	1175·72	2	625·14	3	1084·04		
1	1176·05	2	625·84	4	1084·60		
1	1176·40	1	629·75	3	1085·59		
2	1247·43	1	644·17	4	1085·75	4	1379·8
2	1323·96	2	702·36	1	1134·20	20	1854·7
1	1328·84	3	702·89	1	1134·45	20	1862·7
2	1329·14	3	703·90	1	1135·02		
2	1329·60	3	718·56	1	1238·94		
4	1334·54	2	787·74	1	1242·93		
4	1335·72	2	790·22	2	1492·83		
3	1548·26	1	796·69	2	1494·78		
3	1550·84	3	832·78				
1	1560·34	3	832·95				
1	1560·76	4	833·35				
2	1561·47	4	833·77				
1	1656·33	4	834·48				
2	1657·04	2	835·12				
1	1657·42	4	835·31				
1	1657·96						
1	1658·18						

Some other strong
Al lines used as
rough standards
(wave-lengths by J. A. C.)

TABLE VIII (continued).

(ii) *Standard Wave-Lengths.*

These are mean wave-lengths deduced from the measures in the following tables :—

<i>Carbon.</i>	<i>Oxygen.</i>	<i>Aluminium.</i>
977·02	599·61	
		1379·75
1247·44	629·75	1384·20
1334·58	644·17	1605·85
1335·74		1611·94
	702·34	
1548·23	702·90	1670·81
1550·79	703·89	
		1719·46
	718·58	1721·32
		1725·00
	779·86	
	787·76	1760·10
	790·21	1761·95
	796·62	1763·94
		1765·82
		1767·71
		1854·80 p
		1858·95 p
		1862·84 p
		1935·84

TABLE IX—Mercury.

Int.	λ vac. I. Å.	Remarks.		Int.	λ vac. I. Å.	Remarks.	
		0^1	0^2			0^1	0^2
6	702.6	O		3	923.6		
7	03.90	O	3.90	3	24.3	p.	
7	18.57	O	8.50	0	35.9		
1	40.77		0.8	1	36.4		
1	45.10		5.1	1	37.1		
1	52.9			2	38.0		
1	58.70		8.8	1	39.8		
1	59.43		9.5	3	42.7		
2	60.43		0.4	1	47.6		
1?	61.17		1.3	2	49.7		
1	62.0			2	51.5		
1	63.40		3.5	1	55.4		
2	64.37		4.4	1	56.6		
2	65.20		5.2	4	58.0		
28	72.33		2.3	1	61.4		
1	74.4			0	62.2		
3	75.93		6.0	1	62.8		
4	79.83	O	9.9	2	65.2		
4	87.77	O	7.8	1	66.2		
5	90.20	O	0.2	18	67.6		
3	96.7	O	6.7	1	68.4		
1	802.4			1	69.2		
0	04.9			1	69.7		
0	12.9			18	70.4		
0	21.4			08	71.5		
0	22.7			1	72.6		
6	34.5	O	Fusion of 835 (834.48)		1	74.2	
7	35.3	O	multiplet into (835.22)		1	74.2	
			0^1	0^2	0	75.0	
3	43.2				0	75.7	
1	50.6				1	76.2	
18	55.0				7	77.1	
2	56.9				1	79.3	
0	60.2				1	80.0	
0	85.5				1	80.3	
2	93.1				1	85.0	
1	95.1				0	85.7	
1	96.2				3	87.5	
4	99.1				2	89.0	
0	901.5				4	89.9	N (989.90)
0	03.7				5	91.6	N (991.66)
3	04.2						0^1 0^2
0	04.6				1	92.2	
0	06.8				1	97.1	
2	15.7	N	(915.71)		0	1000.5	
3	16.1	N	(916.13)		1	02.1	
4	16.8	N	(916.82)		1	02.8	
			0^1	0^2	2	09.4	
1	19.7				2	10.3	
3	21.4				1	14.0	
3	22.0				0	15.4	
3	22.6				1	16.4	
4	23.3				1	18.2	
					38	20.2	
					2	25.6	H?
					1	31.8	

TABLE IX—Mercury (continued).

Int.	λ vac. I. Å.	Remarks.		Int.	λ vac. I. Å.	Remarks.	
		0 ¹	0 ²			0 ¹	0 ²
1δ	1033·3			2	1122·0		
2	34·7			2	25·3		
1	35·7			0	26·4		
1	36·4			0	26·7		
2	37·2			1	28·4		
0	37·7			0	29·3		
1	39·1		519·54 ?	1	32·6		
2	39·8		519·88 ?	1δ	34·3	N (1134·33) unresolved	
3	43·8					pair.	
2δ	45·8			1δ	35·2	N ? (1135·02)	
1	47·3						
1	51·3						
1	51·6			2	36·9		0 ¹ 0 ²
0	57·5			1	37·9		
1	58·1			1	38·7		
1	58·9			1	39·2		
2	61·6			2	42·9		
3	62·8			0	43·5		
0	64·2			0	44·2		
0	65·5			0	45·0		
1	66·8			2	45·8		
0	71·2			2	46·3		
1	71·8			3	48·9		
2	72·8			0	50·5		
4	80·1			0	51·0		
4	82·8			1δ	51·9		
3	84·0	N (1084·04)		1	52·6		
3	84·7	N (1084·60)		1	53·3		
5	85·7	N (1085·67) unresolved		1	53·8		
		pair.		1	54·5		
				0	55·4		
		0 ¹	0 ²	1δ	56·6		
0	87·5			2	57·6		
1	89·9			2	58·3		
1	90·1			1	60·4		
1	91·0			0	62·0		
1	92·1			1	62·6		
0	92·9			1	64·0		
3	93·5			0δ	64·7		
0	95·2			1	67·6		
0	96·0			1δ	70·8		
1	98·1			0	73·9		
1	99·6			1	75·0		
2	1101·6			2	75·7		
2	02·1			2	76·4		
3	03·7			1	77·0		
1	05·1			0	80·8		
1	05·6			0	81·2		
1δ	06·9			1	83·8		
1δ	08·4			1	84·5		
5	10·1			2δ	87·8		
1	10·6			0	91·9		
3δ	13·2			0	92·4		
3	14·3			0	94·1		
1δ	15·5			0	95·6		
1	21·3			3	1206·6		

TABLE IX—Mercury (continued).

Int.	λ vac. I. Å.	Remarks.	Int.	λ vac. I. Å.	Remarks.
		0 ¹ 0 ²			0 ¹ 0 ²
3	1212.9	d.	2	1305.6	
4	15.8	H (1215.68)	1	07.9	
		0 ¹ 0 ²	1	10.4	
1	16.8		1	11.2	
18	19.6		1	12.8	
1	21.5		1	13.5	
0	23.3		0	20.4	
0	23.9		1	21.0	(Lyman 1321.4)
0	25.8				0 ¹ 0 ²
1	26.8		1	21.8	
2	31.9		3	23.3	
1	33.9		38	26.5	
1	35.4		4	30.8	
0	37.7		1	31.8	
2	38.8		1	34.2	
2	39.8		1	34.6	C (1334.54)
28	41.7		3	35.2	
1	43.0	d	3	35.8	C (1334.72)
1	44.7				0 ¹ 0 ²
1	45.7				
18	47.6		2	38.7	
0	49.2		2	39.9	
2	50.3		1	42.3	
2	51.1		28	43.7	
2	51.7		1	44.4	
1	54.0		0	45.9	
1	58.8		0	46.6	
2	59.5		1	50.3	
18	63.7		28	53.0	
18	64.7		2	60.5	
18	66.1		1?	61.0	
4	69.8		2	61.4	
0	72.9		0	62.4	
3	77.2		1	67.2	
0	79.7		0	70.1	
4	80.8		1	71.2	
0	82.4		1	71.8	
1	84.8		0	72.7	
1	88.3	O (644.17) ?	0	73.2	
		0 ¹ 0 ²	3	77.9	
1	90.1		3	79.1	
1	90.6		4	79.8	Al (1379.8)
0	91.5		1	83.3	
1	92.9		5	84.3	Al (1384.16)
1	94.6				0 ¹ 0 ²
0	95.4		0	86.4	
0	96.1		1	91.8	
2	96.9		1	93.1	
0	97.8		5	93.9	
2	98.9		1	95.6	
1	1302.1		0	97.8	
1	03.1	d	3	1400.6	
1	04.1		4	02.9	
1	04.9		0	09.3	

TABLE IX—Mercury (continued).

Int.	λ vac. I. Å.	Remarks.		Int.	λ vac. I. Å.	Remarks.	
		0 ¹	0 ²			0 ¹	0 ²
0	1412.5			1	1549.8		
0	13.7			2	50.8	C (1550.88)	
4	14.5					0 ¹	0 ²
4	15.0			0	56.2		
3	17.1			0	58.6		
1	22.2			1	60.6		
1	24.4			2	61.5		
0	28.6			1	69.6		
0	29.8			0	73.2		
0	30.2			0	78.2		
0	34.2			0	84.8		
0	35.0			0	87.3		
0	35.9			0	91.2		
2	36.6			5	92.9	(possibly fused with 0 ² of O (796.69)).	
3	42.7					0 ¹	0 ²
2	45.5			0	95.8		
1	47.5			4	99.4		
2	48.3			8	1605.9	Al (1605.83)	
4	54.2			8	11.9	Al (1611.93)	
1	55.7					0 ¹	0 ²
1	59.4			1	23.9		
3	61.4			1	32.5		
3	65.8			0	38.3		
1	66.9			1	39.4		
2	67.5			7	47.4		
2	68.7			8	49.9		
3	72.5			2δ	54.6		
1	73.4			2	57.1	p.	
2	75.9			1	58.1	p.	
1	79.2			2	62.7		
2	79.9			1	65.3		
0	82.7			1	66.4		
1	85.0			1	67.3		
2	88.3			1	68.6		
1δ	91.2			10	70.7	Al (1670.83). (Probably confused with Hg 1671.0 (Lyman)).	
2	92.7	N ?				0 ¹	0 ²
2	93.8	N ?					
4	95.3	(Lyman 1495.0)					
		0 ¹	0 ²				
3	1507.4			6	77.8		
0	09.5			1	92.7		
1	11.0			0	94.9		
1	11.7			6	1719.3	Al (1719.50)	
2	13.8			7	21.2	Al (1721.28)	
1	16.9			8	24.9	Al (1725.01)	
0	20.4					0 ¹	0 ²
2	25.4			4	38.3	d ?	
3	27.5			1	40.4		
1	31.6			0	41.2		
1	33.3			0	42.7		
1	33.9			4δ	49.8		
2	39.9			8	59.8	Al (1760.12)	p.
2	40.5						
0	45.5						
3	48.2	C (1548.32)					

TABLE X—Gallium.

Int.	λ vac. I. Å.		Remarks.		Int.	λ vac. I. Å.		Remarks.	
			0 ¹	0 ²				0 ¹	0 ²
1	599.60	O	9.63	9.58	0	868.7			
2	629.79	O	9.69	9.84	4	74.4			
3	702.6	O	2.85	2.33, 2.91 :	3	75.6			
				double.	0	78.2			
3	03.86	O	3.92	3.83	0	80.4			
3	18.66	O	8.61	8.69	0	81.0			
2	58.41		8.49	8.37	0	84.4			
1?	59.4				3	89.3	9.27	9.05?	
3	60.41		0.44	0.39	1	92.5			
2	62.01		1.94	2.04	0	97.6			
1δ	65.10		5.01	5.15	1	98.9			
2	66.8				1	900.3			
2	68.4		d?		1	01.3			
					4δ	04.08	4.13	4.06	
			0 ¹	0 ²	3	08.29	8.23	8.32	
1	69.8				3	09.34	9.49	9.26	
2	71.2	N?			4	11.32	1.45	1.26	
2	72.8	N?			1	12.4			
1	74.6				1δ	13.9			
2δ	76.9				1δ	15.9			d?
3	77.91		7.90	7.91	1	18.1			
2δ	78.3				2	20.1			
3	79.83	O	9.87	9.81	4	21.42	1.53	1.36	
2	81.74		1.67	1.77	1δ	22.9			d?
1	84.8				1	26.6			d?
2	86.8				3	27.8			
3	87.81	O	7.83	7.80	3	30.0			
4	90.22	O	0.13	0.26	0	31.0			
1	92.4				1	33.0			
1	92.9				2	34.0			
3	95.23		5.28	5.20	4	35.73	5.83	5.67	
1δ	96.6	O	6.76	6.43?	4	38.6	8.60	8.91?	
2	98.75		8.75	8.75	2	40.9			
3	800.48		0.50	0.47	3δ	43.0			
0	02.7				0?	45.1			
2	03.9				4	47.15	7.16	7.14	
2	04.5				3?	47.8			
3	06.6				2	49.5			
1	09.6				5	51.98	1.93	2.02 (A), 1.96 (B)	
1δ	11.3				2	53.8			
1	12.9				1	55.4			
1	15.3				5	56.92	6.91	6.93	
3δ	17.28		7.31	7.26	0	57.8			
1	23.5				1δ	61.7			
2	28.8				1	63.6			
4	34.4	O	4.40	0.835 group un- resolved.	6	65.3	5.30	5.25, 5.52 double	
4	35.4	O	5.37			1δ	67.4		
2	39.86		9.87	9.86	2	70.0			
1	41.1				3	73.2			
0	49.4				1δ	74.9			
2	55.9				6δ	76.7			
1	57.8								Not in 2nd order. Possibly a fusion with 977.02 of C.
3	60.4				2	79.4			
1	64.8				2	80.4			

TABLE X—Gallium (continued).

Int.	λ vac. I. Å.	Remarks.		Int.	λ vac. I. Å.	Remarks.	
		0^1	0^2			0^1	0^2
4	981.84	1.88	1.82	1	1087.28	7.28	7.28
1	84.0			1	90.4		
1	85.6			2	91.67	1.68	1.67
3	86.81	6.76	6.84	2	94.28	4.18	4.33
2 δ	87.6			2	95.09	5.01	5.13
3	89.6			1	1100.34	0.25	0.38
3	90.8			1	01.58	1.51	1.61
3	93.0	Imperfectly resolved triplet.		4	02.89	2.88	2.90
2	96.3			1 δ	05.4	5.39	4.16, 4.95, 5.57, 6.13 (un- resolved multiplet).
1	99.9						
		0^1	0^2			0^1	0^2
1	1002.9			1	07.72	7.67	7.74
3	04.1			1	10.5		
1	06.5			1 δ	13.1		
1	08.8			1	15.4		
3	10.0			3	18.27	8.15	8.33
1	11.1			3	20.78	0.73	0.81
3	14.43	4.38	4.45	3 δ	23.3	3.26	3.11, 3.66 (un- resolved doublet).
2	14.6						
2	17.3						
3 δ	19.66	9.61	9.71				
0	20.7					0^1	0^2
2	22.1			3	26.32	6.30	6.33
1	23.0			3 δ	28.3	8.09	8.08, 8.49 (un- resolved doublet ?).
0	25.4						
2	26.6					0^1	0^2
1	28.9			1	29.84	9.75	9.88
1	30.3			1	31.6	1.63	1.43, 2.14 (un- resolved doublet ?).
1	32.0						
1	33.5					0^1	0^2
1	35.0			3	33.79	3.75	3.81
1	35.9			2	36.01	5.92	6.05
0	37.1			2	36.99	6.94	7.02
1	38.7			2	38.09	8.12	8.07
0	40.2			0 ?	43.1		
1	42.4			2	44.22	4.24	4.21
0	44.9			3	45.70	5.76	5.66
1	45.9			0	48.4		
1	47.4			4	50.23	0.22	0.23
4	50.40	0.48	0.36	4	56.3	6.22	6.15, 6.49 (un- resolved doublet ?).
0	52.3						
2	54.47	4.42	4.50			0^1	0^2
3	58.09	8.08	8.09	0 ?	57.4		
3 δ	62.64	2.59	2.66	0	58.5		
0	63.5			0	60.6		
2	66.68	6.62	6.71	0	62.0		
1 ?	67.6			4	63.58	3.61	3.57
1	68.5			5	70.57	0.60	0.56
2	69.57	9.56	9.57	1	72.4		
2	71.13	1.08	1.16	1	73.4		
2	73.73	3.69	3.75	3 δ	75.69	5.74	5.66
2	78.75	8.60	8.82 ?	1	78.7		
2	79.59	9.54	9.61				
1	80.8						
5	84.98	4.95	4.99				

TABLE X—Gallium (continued).

Int.	λ vac. I. Å.	Remarks.	Int.	λ vac. I. Å.	Remarks.
		0 ¹ 0 ²			0 ¹ 0 ²
0	1183.5		0	1319.1	
4	85.20	5.19 5.20	4	23.17	3.22 3.14
4	90.81	0.75 0.84	0	26.6	
4	92.99	3.00 2.98	1	28.5	
4	95.02	5.03 5.02	1	30.6	
0?	96.0		0	35.0	
1	97.6		0	35.9	
3	1201.55	1.58 1.54	6	38.15	8.17 8.14
4δ	06.9	6.85 6.48, 6.90 (un- resolved doublet?).	0?	40.2	
		0 ¹ 0 ²	0	41.7	
1	07.9		1δ	43.8	
0	10.1		3	47.09	7.18 7.05
1	13.2		0	48.1	
2	15.69	5.77 5.65	0	50.0	
0	17.6		2	51.2	
0	19.6		0	53.1	
0	22.2		4δ	53.98	4.01 3.97
0	23.1		0	56.2	
6	28.01	8.04 7.99	0	57.9	
0?	28.9		0	59.8	
0	38.1		0	61.2	
0	31.4		0	62.7	
0	34.0		0	64.0	
3	36.40	6.42 6.39	3	64.73	4.85 4.68
3	38.58	8.56 8.59	0	69.6	
0	41.6		0	71.25	1.28 1.23
0?	43.4		0	73.2	
4	45.56	5.61 5.53	0	75.4	
1	46.5		0	77.7	
1δ	49.9		3	79.74	Al 9.80 9.70
1δ	51.5		1	81.9	
0	53.3		3	84.16	Al 4.24 4.12 (1384.16)
0	54.4		0	87.6	
7	58.81	8.82 8.80	0	91.5	
0?	60.7		3	93.74	3.81 3.70
0	62.2		3	95.58	5.67 5.53
4	64.64	4.63 4.65	3	1402.88	2.85 2.89
6	67.19	7.22 7.17	10	14.49	4.43 (A) 4.66 4.45 (B)
0	72.8		0	30.1	
0	76.9		0	32.2	
5	79.30	9.29 9.30	0	35.2	
5	85.39	5.36 5.40	0	39.7	
6	93.46	3.45 3.46 (possibly a very faint close companion).	0	43.5	
		0 ¹ 0 ²	0	46.5	
1	95.29	5.17 5.35	2	49.3	
6	95.91	5.88 5.93	0	50.9	
6	99.49	9.52 9.48	3	55.0	
6δ	1303.56	3.60 3.54	0	56.9	
0	06.7		5	63.59	3.69(A) 3.40 (B)
5	09.73	9.78 9.71	1	66.0	
4	14.86	4.89 4.85	5	73.8	
0	18.1		6	83.96	3.93(A) 3.99 (B)
			0	86.1	
			0	87.8	
			0	91.0	

TABLE X—Gallium (continued).

Int.	λ vac. I. Å.	Remarks.	Int.	λ vac. I. Å.	Remarks.
		0 ¹ 0 ²			0 ¹ 0 ²
0	1492.3		3	1644.79	4.83(A)4.74(B)
12	95.36	5.28(A)5.51(B)	0	45.7	
0	99.5		2	47.5	
0	1500.7		5	50.0	
5δ	04.7		1	50.9	
0	12.9		2	51.8	
5δ	14.7		0	53.4	
0	25.3		0	54.9	
1	29.0		0	56.32	C (1656.33)
14	34.65	4.65(A)4.64(B)	2	57.12	C (1657.04)
0	35.5		0	58.13	C (1658.18)
0	36.4		0	60.0	
0	39.9		2	65.66	O 0 ² of 832.83 (832.86)
0	44.8		2	66.67	O 0 ² of 833.34 (833.35)
2	46.9		2	67.61	O 0 ² of 833.81 (833.77)
3	48.27	C (1548.26)	2δ	69.08	O 0 ² of 834.59 (834.48) (835.2 present, but not measurable.)
3	50.82	C (1550.84)			
2δ	52.3		12	70.88	AI 0.90(A) 0.83(B) (1670.8)
2δ	54.4				
1	57.2		1	71.7	
1	58.7		3	73.04	3.03(A)3.06(B)
2δ	60.9		3	74.15	4.13(A)4.19(B)
2	62.5		1	75.8	
2	66.7		2	77.9	
2	69.8		0	81.9	
0	71.7		2	88.6	
5	74.7		0	95.7	
1δ	77.3		0	98.5	
1	79.3		4	1700.02	0.03(A)9.99(B)
4	81.6		2	02.5	
1	82.3		2	06.7	
0	84.1		1	11.6	
1	84.9		0	15.3	
8	86.39	6.37(A)6.44(B)	2	16.52	6.52(A)6.53(B)
0	87.3		6	19.49	AI 9.44(A)9.53(B) (1719.50)
0	88.0				
1δ	95.1		7	21.33	AI 1.33(A)1.32(B) (1721.28)
2	98.5				
0	99.4		8	25.05	AI 5.02(A)5.08(B) (1725.01)
9	1605.81	AI 5.86(A)5.78(B) (1605.83)			
1δ	07.4		0 ?	28.0	
10	11.95	AI 1.98(A)1.94(B) (1611.93)	0	29.5	
			0	37.3	
3	19.6		1	38.7	
3	22.5		3	41.5	
7	25.37	5.37(A)5.38(B)	0	42.6	
1	26.2		0	44.2	
3	29.22	9.21(A)9.23(B)	0	46.2	
1	30.1		0 ?	47.4	
0	31.4		8	48.75	8.76(A)8.73(B)
0	32.9		2	49.87	9.80(A)9.94(B)
0	36.9		0	51.1	
6	39.35	9.30(A)9.45(B)	0	52.1	
0	40.1		0	56.2	
0	41.6				

TABLE X—Gallium (continued).

Int.	λ vac.		Remarks.	Int.	λ vac.		Remarks.
	I. Å.				I. Å.		
			0 ¹ 0 ²				0 ¹ 0 ²
6	1760·10	Al	0·07(A)0·13(B) (1760·12)	0	1889·9		
6	61·94	Al	1·90(A)1·98(B) (1761·96)	0	92·8		
7	63·93	Al	3·93(A)3·92(B) (1763·95)	1	1909·0		
6	65·78	Al	5·76(A)5·79(B) (1765·81)	78	35·82	Al Plate B from here on. (1935·83)	
6	67·68	Al	7·65(A)7·70(B) (1767·75)	1	42·3		
0	69·0			0 ?	53·0		
5	70·54		0·49(A)0·59(B)	28	66·7		
0	72·8			0	77·2		
1	73·8			18	79·5		
2	74·77		4·74(A)4·80(B)	18	81·7		
2	77·0		6·90(A)7·13(B)	7	90·4		
0	78·1			8	2026·1		
0	85·1			68	62·6		
7	99·31		9·28(A)9·34(B)	38	64·8		
9	1802·32		2·32(A)2·26(B)	38	79·1		
0	09·6			48	91·4		
0	11·9			0	2266·4		
9	13·91		3·92(A)3·90(B)	0	81·3		
0	29·4			4	97·50	C (2297·57)	
0	33·0			0	2306·6		
0 ?	35·1			1	63·1		
0	36·2			68	2418·6		
0 ?	38·9			78	24·9		
0	40·0			1	98·29	O 0 ³ of 832·76	
9	45·28		5·28(A)5·27(B)	1	98·85	O 0 ³ of 832·95	
20	54·75	Al	4·80(A)4·69(B) (1854·7) p.	2	2500·01	O 0 ³ of 833·34	
38	57·9	Al	7·75(A)7·99(B)	2	01·27	O 0 ³ of 833·76	
20	62·72	Al	2·75(A)2·68(B) (1862·9) p.	2	03·36	O 0 ³ of 834·45	
0	65·7			2	05·85	O 0 ³ of 835·29	
0	67·3			0 ?	61·7		
0	69·1			0	2661·9		
0	75·3			0	69·08	C 0 ² of 1334·54	
0	81·4			1	71·42	C 0 ² of 1335·71	
				1	87·0		
				0	2701·6		
				0	03·8		
				0	05·8		
				38	80·7		

Wave-lengths (λ air I. Å) from the plate taken with Anderson's apparatus.

Iron comparison spectrum.

Int.	λ air.		Remarks.	Int.	λ air.		Remarks.
	I. Å.				I. Å.		
			0 ¹ 0 ²				0 ¹ 0 ²
4	2296·89	C		1	58·07		8·11 8·06
5	2417·95		7·97 7·94	3	2631·68		1·77 1·63
5	24·26		4·31 4·24	3	2700·66		0·72 0·63
2	78·68		8·75 8·65	6	80·22		
0	2509·20		9·23 9·18	5	2816·41	Al	
2	12·15		2·18 2·14	1	36·87		

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TABLE X—Gallium (continued).

Int.	λ air.		Remarks.	Int.	λ air.		Remarks.
	I. Å.				I. Å.		
			0 ¹ 0 ²				0 ¹ 0 ²
0	2837·81			5	3943·94		
3	74·41			5	61·48		
5δ	2943·75			8	4033·03		
0	44·24			00	67·84		
2	3082·21	AI		00	68·81		
4	92·79	AI		0δ	70·05		
0	3302·59			0	72·07		
2	45·06			0	75·83		
6	75·05			0	88·78		
3	75·93			00	4101·70		
00 ?	87·66			5	50·08	AI	
0	3451·26			10	72·14		
8	3517·44			0	86·76		
1	30·56			8	4251·18		
0	70·83			4	54·13		
9	77·37			8	55·75		
3δ	85·44			10	62·05		
4	87·06	AI		1δ	63·09		
8	3601·61	AI		5	67·20		
0	04·97			5	4380·67		
7	12·37	AI		5	81·86		
1	51·09	AI		0	4414·84		
3δ	3702·07	AI		7	79·96	AI	
5	13·13	AI		5	4512·59	AI	
4	30·06			6	29·17	AI	
2	35·27			0	90·70		
0	59·69			0	96·74		
1	66·13			4	4647·50		
0	83·83			0	49·15		
0	87·24			2	50·25		
1	3803·50			0	51·41		
5	06·72			3	63·22	AI ?	
1	74·31			0	80·13		
0	76·09		d ?	1	4722·24		
00 ?	79·43			2	4810·67		
00	3900·56	AI ?		0	49·09		
1	18·88			6δ	63·19		
2	20·56			0	4924·04		
0	33·63			4	94·15		
1	41·44			00	5004·15		

TABLE XI—Indium.

Int.	λ vac. I. Å.	Remarks.	Int.	λ vac. I. Å.	Remarks.
		0^1 0^2			0^1 0^2
2	599.63	O 9.60 9.65 (599.60)	2	1020.1	
1	644.18	O (644.17)	2	24.8	
2	702.30	O (702.36)	3	28.6	
3	02.87	O (702.89)	2	31.5	
3	03.91	O 3.90 3.91 (703.90)	0	33.2	
4	18.58	O 8.63 8.55 (718.56)	1	34.6	
3	79.9	O (779.86)	3δ	36.8	C ? d ? (1036.35, 1037.03)
4	87.75	O 7.73 7.76 (787.74)			
5	90.23	O 0.24 0.22 (790.22)			0^1 0^2
4	96.7	O (796.69)	0	39.5	
5	834.5	O { O 834 group incompletely resolved; approximate measures.	2	43.8	
		0^1 0^2	1	45.8	
5	35.4	O	1	47.1	
0	43.2		3	48.9	
0	50.6		0	52.3	
0δ	54.9		1	54.5	
0	56.9		1	59.8	
0	60.2		1	61.3	
0δ	75.9		1	63.0	
0	78.8		0	71.8	
0	86.4		0	73.0	
1	89.5		2	80.1	
2	99.0		2	82.25	2.26 2.24
5	904.08	4.12 4.06	2	83.0	
1	06.8		0	86.5	
0	15.8		1	97.0	
1	23.4		0	1101.9	
1	33.6		3	09.9	
1δ	36.5		0	13.0	
1	38.0		0	14.2	
1	40.1		0	16.3	
1	42.5		1	22.2	
1	49.7		0	25.4	
1	51.5		2	31.61	1.51 1.66
1	54.6		0	36.4	
1	56.5		0	36.8	
3	57.8		1	37.9	
2	65.1		1	42.9	
0	66.3		0	44.5	
0	67.6		3	46.4	
0	69.6		2	48.85	8.90 8.83 ? d ?
6	77.02	C (977.02)	2	51.7	1.73 (1.88 ?)
		0^1 0^2	1	54.3	
2	87.3		3	57.96	7.97 7.95
1	89.0		0	60.1	
1	92.1		0	62.2	
2	97.0		0	63.9	
2	1010.2		0	67.9	
0	12.4		4δ	75.9	C (1175 group ?) 5.76 ?
0	14.0				0^1 0^2
0	15.5		0 ?	81.1	
0	16.5		0	83.1	
1	18.2		0	84.7	
			0	87.9	
			2	92.62	2.62 2.62

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TABLE XI—Indium (continued).

Int.	λ vac. I. Å.	Remarks.		Int.	λ vac. I. Å.	Remarks.	
		0 ¹	0 ²			0 ¹	0 ²
0	1200.8			1	1417.1		
2	06.62	6.55	6.65	4	30.0		
0	10.20	0.17	0.21	5	35.1		
1	12.9			3	39.8		
3	14.8			2	42.7		
0?	22.61	2.54	2.64	3	46.1		
08	28.09	8.14	8.06	0	48.2		
0	32.0			2	54.3		
0	33.14	3.14	3.14	2	61.4		
0?	35.6			2	65.8		
1	39.75	9.73	9.76	5	72.4		
28	41.27	1.29	1.26	4	81.5		
0?	43.4			7	87.7		
0	45.1		d?	3	94.0		
0?	46.6			2	95.1		
0	47.41	C? (1247.43)		4	1501.8		
		0 ¹	0 ²	1	07.4		
1	51.2			4	09.9		
0	52.91	2.89	2.92	1	13.8		
0	58.9			6	21.7		
0	60.67	0.64	0.69	3	27.4		
08	66.36	6.41	6.34	5	30.2		
1	67.47	7.48	7.46	2	33.6		
2	70.0			2	44.2		
1	77.2			5	45.5		
1	78.85	8.84	8.86	4	48.21	C (1548.26)	
2	80.9			1	50.85	C (1550.84)	
5	95.94	5.97	5.92	1	53.1		
3	1300.61	0.60	0.61	1	58.6	0 ² of 779.30?	
2	05.7			1	61.4	0 ² of 780.70?	
1	10.11	0.19	0.07	1	69.5		
2	13.15	3.14	3.15	1	71.5		
1	15.18	5.21	5.16	3	78.2		
4	20.2	0.15	0.04, 0.56? d?	10	86.4		
2	23.3			6	93.0		
2	26.5			4	99.5		
6	30.9			9	1605.78	Al (1605.83)	
5		C? not measurable, probably 1334.5 of C.		2	07.4		
		0 ¹	0 ²	10	11.90	Al (1611.93)	
						0 ¹	0 ²
1	39.68	9.71	9.67	2	15.8		
5	44.63	4.64	4.62	15	25.3		
5	51.10	1.10	1.10	1	32.6		
1	53.0			0	39.3		
1	55.6			3	40.1		
3	60.5			1	42.2		
2	77.9			0	42.8		
3	79.75	Al	9.76 9.75	8	47.6		
5	81.87		1.88 1.86	10	50.0		
5	84.18	Al	4.18 4.18 (1384.16)	0	52.4		
4	93.90		3.96 3.87	0	53.1		
5	1403.07		3.05 3.09	2	54.7		
5	06.20		6.14 6.23	0	56.3		
4	14.9			0	56.9		
				0	57.4		

TABLE XI—Indium (continued).

Int.	λ vac.		Remarks.	Int.	λ vac.		Remarks.
	I. Å.				I. Å.		
0	1658.1			20	1862.83	AI	0^1 0^2 2.84(A)2.82(B) (1862.90)
0	59.9			2	69.2		
4	62.7			1	1908.9		
2	65.58		O ? 0^2 of 832.79 (832.95)	1	31.0		B
2	66.62		O ? 0^2 of 833.31 (833.35)	2	31.7		A
2	67.52		O ? 0^2 of 833.76 (833.77)	7	35.86	AI	B (1935.83)
10	70.80		AI (1670.83)	3	36.8		A
6	74.1						
8	78.0						
1	81.3						
1	82.1						
1	92.6			4	66.7		From here on plate B only. Probably some uniden- tified 2nd order lines are present. (1966.69 Saunders) (1977.44 Saunders)
6	1700.0			3	77.3		
5	02.5						
5	16.6			4	90.5		
6	19.47		AI (1719.50)	4	2079.3		(2079.28 Saunders)
7	21.29		AI (1721.28)	1	2293.5		
8	25.00		AI (1725.01)	1	97.65		C ? (2297.57) 0^2 of 1148.83 ?
0	32.7			1	2303.8		0^2 of 1151.90 ?
0	35.3			4	06.5		
0	36.1			4	07.1		
4	38.5			1	36.5		
2	40.2			28	51.51		0^2 of 1175.76 ?
4	41.6			1	2434.6		
15	48.8			1	2552.8		
0	56.0			1	71.1		
6	60.11		AI (1760.12)	1	73.6		
6	61.98		AI (1761.96)	2	79.7		
7	63.97		AI (1763.95)	1	81.0		
5	65.87		AI (1765.81)	1	85.4		
6	67.78		AI (1767.75)	1	86.6		
6	70.6			1	90.3		
4	74.8			1	2635.5		
48	77.2			4	40.07		0^2 of 1320.04, 1320.56 ?
4	96.2			1	41.12		
3	98.7			4	67.7		Prob. 0^2
0	1802.4			4	68.11		C 0^2 of 1334.56 (1334.54)
0	03.9			2	71.46		C 0^2 of 1335.73 (1335.72)
3	10.5			3	2711.0		
28	18.5			1	26.8		
2	20.6			1	44.1		
2	22.0			1	44.9		
2	26.0			2	47.1		
2	50.18		0.11(A)0.24(B)	2	2811.3		
20	54.75		AI 4.69(A)4.81(B) (1854.67)	0	17.6		
2	58.01		AI 8.00(A)8.01(B)				

TABLE XI—Indium (continued).

Wave-Lengths (λ air I. Å.) from a plate taken with Anderson's apparatus.
Iron comparison spectrum.

Int.	λ air. I. Å.	Remarks.		Int.	λ air. I. Å.	Remarks.	
		0 ¹	0 ²			0 ¹	0 ²
5	2631·77	Al	(2631·77)	1	2928·04		
1	2715·71			0	30·77		
0	16·94			2	33·27		
1	26·27		d	0	35·11		
0	63·07			6	38·71		
2	73·04			6	39·36		
5	86·25			9	41·14		
1	92·73			0	43·66		
1	95·56			0	65·24		
1	2810·90			0	72·88		
1	11·95			7	79·58		
10	16·14	Al		12	82·93		
0	32·97			1	86·92		
1	39·33			1	89·59		
1	44·51			0	91·54		
0	55·98			14	3008·31		
3	60·52			1	22·72		
2	64·23			1	33·65		
0	69·60			5	37·11		
0	80·12			2	38·67		p.
0	83·57			5	39·35		
8	90·21			3	47·00		
0	94·43			1	52·34		
7	2900·56			4	56·61		
1	05·16			3	66·56		
1	06·01			0	74·44		
1	07·08			4	78·27		
1	07·93			2	81·05		
3	10·52			4	82·20	Al	(3082·19)
2	11·45			3	83·45		
1	15·62			8	92·73	Al	(3092·76)
1	27·06			0	3100·65		

TABLE XII—Thallium.

Int.	λ vac. I. Å.	Remarks.				Int.	λ vac. I. Å.	Remarks.		
		0 ¹	0 ²	0 ³	0 ⁴			0 ¹	0 ²	0 ³
3	977.02 C	7.06	7.00	(977.02)	977.10?	0	1157.7	7.66	7.84 ?	
2	93.66	3.66	3.66			0	58.62	8.66	8.60	
1	95.5					00	60.7			
4	1028.55	8.57	8.52	8.55	8.56	4	62.77	2.74	2.84	2.74
3	30.86	0.89	0.87	0.86		00	65.23	5.28	5.20	
0	31.7					00	66.4	6.39	(6.53 ?)	
3	34.74	4.73	4.71	4.74	4.77	00	67.49	7.48	7.49	
3	36.60 C ?	6.63	6.55	6.61	6.62	1	70.00	9.99	0.01	
1	37.73	7.77	7.71	7.72		00	71.56	1.48		1.58
3	44.25	4.26	4.21	4.24	4.27	0	75.10 C ?	5.03	5.13	
1	46.02	6.09	5.98			1	75.86 C ?	5.87	5.86	5.85
1	48.86	8.81		8.88	8.86	1	76.50 C ?	6.49	6.51	6.50
2	49.48	9.49	9.47	9.49	9.48	2	79.2			
00	50.39	0.47	0.35			0	80.12	0.09	0.13	
0	53.5					0	82.31	2.26	2.34	
00	54.80	4.82	4.79	4.80		1	83.59	3.60	3.58	
1	56.34	6.31	6.37	6.37	6.32	00	86.30	6.29	6.30	
2	57.56	7.50	7.56	7.58	7.55	00	87.6	7.59	(7.78 ?)	
00	58.2					2	88.61	8.63	8.60	
00	59.9					0	90.68	0.69	0.67	
3	65.15	5.19	5.22	5.17	5.10	1	92.18	2.20	2.17	
4	68.11	8.14	8.15	8.08	(7.99?)	0	93.49	3.55	3.46	
4	70.48	0.57		0.49	0.44	00	95.3			
0	72.75	2.81	2.71			00	97.71	7.72	7.71	
0	73.69	3.67	3.79	3.71	3.63	3	1201.64	1.64	1.62	1.66
3	74.56	4.59	4.59	4.53	(4.46?)	1	09.07	9.04	9.09	
00	78.5					00	10.1			
6	79.71	9.69	9.79	9.70	9.67	00	11.9			
4	82.68	2.68	2.72	2.66		0	14.29	4.26	4.31	
2	87.71	7.69	7.71	7.72		0	15.75 H ?	5.74	5.76	
4	90.70	0.71	0.72	0.69		0	16.54	6.53	6.54	
2	92.90	2.83	2.94	2.89		0	18.5			
0	94.65	4.67	4.64			2	21.05	1.05	1.05	
6	99.60	9.61		9.59		0	21.98	1.91	2.01	
2	1102.19	2.22	2.19	2.18		00	23.03	2.91	3.09	
1	03.69	3.65	3.71			00	23.84	3.80	3.86	
0	05.9		5.34 ?			2	25.45	5.39	5.45	5.46
4	09.43	9.44	9.44	9.42		0	26.5			
0	12.0					00	27.51	7.53	7.50	
0	13.7					6	31.57	1.59	1.55	1.58
2	18.89	8.75	8.89	8.93		1	34.25	4.20	4.28	
2	19.71	9.77	9.75	9.67		00	36.54	6.47	6.58	
1	20.88	0.91	0.87	0.88		2	37.48	7.62	7.41	
4	25.52	5.53	5.52	5.51		00	40.36	0.42	0.33	
0	27.90	7.89	7.90			00	42.9	2.78	2.94	
4	34.32	4.35	4.31	4.31		1	43.82	3.81	3.83	
0	37.29	7.33	7.27			0	46.00	5.91	6.04	
5	39.30	9.33	9.28	9.30		0	46.60	6.55	6.62	
1	41.9	d. ?	(1.79 ?)	1.73,	2.16 ?	0	47.60	7.70	7.54	
3	44.07	4.05	4.05	4.09		2	49.56	9.55	9.57	
00	47.2					2	50.93	0.96	0.91	
00	48.3					1	52.65	2.63	2.66	
00	50.2					0	54.26	4.25	4.26	
2	53.22	3.21	3.22			0	57.32	7.31	7.32	
0	55.59	5.57	5.60			0	58.24	8.25	8.23	
0	56.40	6.37	6.41			1	59.32	9.26	9.36	

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TABLE XII—Thallium (continued).

Int.	λ vac. I. Å.	Remarks.			Int.	λ vac. I. Å.	Remarks.		
		0 ¹	0 ²	0 ³			0 ¹	0 ²	0 ³
0	1260.21	0.18	0.23		0	1407.4			
1	61.13	1.12	1.13		0	08.6			
2	63.55	3.56	3.55	3.54	5	12.93	2.91	2.93	
8	66.33	6.42	6.29	6.33	1	22.8			
0	71.45	1.40	1.48		1	24.63	4.68	4.61	
3	73.03	3.04	3.02	3.02	0	27.0			
1	76.37	6.32	6.38	6.38	0	28.3			
1	78.68	8.78	8.63		0	30.8			
0	81.37	1.37	1.37		6	34.71	4.73	4.70	
0	82.83	2.84	2.82		1	44.9			
00	83.91	3.91	3.91		00	48.0			
0	85.51	5.57	5.48		5	49.37	9.41 (A), 9.33 (B)		
2	86.98	6.85	7.01	7.00	3	57.17	7.24 (A), 7.10 (B)		
1	92.7				00	58.6			
1	95.59	5.61	5.58		2	60.67	0.65 (A), 0.68 (B)		
3	1304.55	4.48	4.54	4.57	0	62.2			
0	05.51	5.45	5.53	5.51	1	64.5			
00	07.66	7.71	7.63		2	69.59	9.57 (A), 9.60 (B)		
2	08.50	8.50	8.52	8.49					
1	09.51	9.45	9.53	9.51					
1	13.20	3.26	3.17		9	76.94	6.98 (A), 6.93 (B)		0 ²
0	15.19	5.12	5.23		0?	85.1			
0	16.09	6.12	6.08		0	87.50	7.47 (A), 7.53 (B)		
2	17.77	7.73	7.78	7.78	6	90.35	0.35 (A), 0.34 (B)		0.36
7	21.72	1.78	1.70	1.72	0	95.3			
1	23.76	C?	3.81	3.73	6	99.19	9.24 (A), 9.15 (B)		9.18
00	25.52		5.42	5.57	0	1502.05	1.97 (A), 2.12 (B)		
0	26.93		6.94	6.93	1	03.82	3.78 (A), 3.83 (B)		3.84
2	30.41		0.36	0.41	4	06.21	6.18 (A), 6.25 (B)		6.21
4	32.36		2.36	2.35	4	07.70	7.72 (A), 7.67 (B)		7.71
2	34.59	C	4.53	4.60	1	09.23	9.18 (A), 9.24 (B)		9.25
				(1334.54)	1	11.27	1.26 (A), 1.28 (B)		1.27
				(1335.72)	1	32.37	2.36 (A), 2.38 (B)		2.38
3	35.79	C	5.87	5.78	2	34.33	4.31 (A), 4.36 (B)		4.32
					7	38.04	8.04 (A), 8.04 (B)		8.04
4	37.19		7.19	7.20	3	48.21	8.18 (A), 8.27 (B)		8.19
2	38.71		8.68	8.72	2	50.75	0.69 (A), 0.80 (B)		0.76
0	44.66		4.59	4.69	1	53.09	3.15 (A), 3.02 (B)		
0	48.5		8.46	(8.69?)	3	54.01	4.04 (B)		4.00
1	49.47		9.38	9.48	15	58.60	8.68 (A), 8.59 (B)		8.57
5	58.58		8.56	8.60	8	61.49	1.52 (A), 1.51 (B)		1.46
3	67.72		7.67	7.72	1?	64.0			
0	70.02		9.95	0.06	1	65.6			
4	70.88		0.90	0.86	6	68.45	8.47 (A), 8.44 (B)		8.44
00	73.61		3.67	3.58	4	71.96	1.96 (A), 2.00 (B)		1.94
5	74.62		4.59	4.59	0	79.1			
7	77.75		7.78	7.72	1	80.63	0.62 (A), 0.63 (B)		
1	81.34		1.30	1.31	0	84.9	4.72 (A), 5.07 (B)		
3	82.70		2.63	2.71	0?	88.5			
00	85.85		5.84	5.86	3	93.13	3.10 (A), 3.17 (B)		3.12
00	87.1				0?	94.5			
3	91.91		1.95	1.84	0?	95.8			
1	94.83		4.80	4.84	6	96.95	6.87 (A), 6.99 (B)		6.97
1	95.80		5.81	5.79	1	98.4			
1	97.00		7.02	6.93	0	99.6			
3	1401.60		1.55	1.63	5	1602.38	2.30 (A), 2.41 (B)		2.40
8	04.60		4.61	4.58					

TABLE XII—Thallium (continued).

Int.	λ vac. I. Å.	Remarks.		Int.	λ vac. I. Å.	Remarks.	
			0^2				0^2
0	1606.0			5	1784.97	4.91 (A), 5.02 (B)	
00	11.9			3	89.6		
0	18.6	8.49 (A), 8.72 (B)		9	93.04	3.03 (A), 3.03 (B)	3.05
0	21.88	1.78 (A), 1.98 (B)		5	98.6		
6	23.3			3	1801.7		
				5	04.4		
2	33.18	3.14 (A)	3.20	2	05.4		
7	34.0			1 ?	08.3		
1	37.6			1	09.7		
4	40.1			10	15.02	4.98 (A), 5.09 (B)	5.01
2	41.8			1	22.9		
6	43.82	3.75 (A)	3.86	4	25.26	5.19 (A), 5.23 (B)	5.32?
1	46.5			6	28.09	8.13 (A), 8.00 (B)	8.11
5	47.2			3	31.67	1.70 (B)	1.66
3	48.2			0	34.3		
1	50.0			2	37.65	7.67 (A), 7.63 (B)	
9	50.1			4	54.91	4.89 (A), 4.87 (B)	4.92
0	51.4			3	61.6		
1 ?	52.8			2	62.95	2.91 (A), 2.98 (B)	
4	53.9			1	65.9		
0 ?	56.87	6.92 (A), 6.82 (B)		1	66.9		
0	59.1			0	69.1		
10	60.06	0.05 (A)	0.06	3	71.56	1.67 (A), 1.53 (B)	1.52
3	61.0			1	73.5		
2	63.7			1	75.0		
1	71.2	1.73 (B) ?		1	77.8		
2	73.0			7	81.28	1.27 (A), 1.24 (B)	1.31
5	74.1			5	82.7		
3	74.4			5	83.2		
5	74.67	4.72 (B)	4.64 ?	0 ?	88.1		
0	77.1			10	92.90	3.06 (A), 2.86 (B)	2.88
0	78.0	8.02 (B)	(7.71 ?)	20	1908.75	9.40 (A) p., 8.74 (B)	8.75
0	80.3			1	13.0		
1	82.29	2.30 (A), 2.28 (B)		1	16.5		
1	85.5			1	17.1		
0 ?	91.4			00 ?	18.2		
1	93.47	3.51 (A), 3.42 (B)		0	19.8		
1	93.9			0	21.5		
1	96.1			0 ?	22.1		
0	99.4			0	22.8		
5	1701.36	1.25 (A), 1.47 (B)		0	23.6		
4	03.4			1	30.7		
3	05.7			1	31.3		
4	08.1			1	33.5		
00	09.5			00 ?	34.8		
2	10.89	0.92 (A), 0.86 (B)		0	36.8		
2	11.3			0 ?	40.6		
3	15.0			2	42.5		
00 ?	21.4			3	64.6	d ?	
3	23.3			00 ?	74.7		
0	25.1			00 ?	89.1		
3	29.75	9.52 (A), 9.81 (B)	9.83	00	99.1		
1	34.0			18	2004.9		
0 ?	36.7			18	20.6		
00 ?	44.3			18	26.2	d ?	
00 ?	47.8			0	52.4		

TABLE XII—Thallium (continued).

Int.	λ vac. I. Å.	Remarks.		Int.	λ vac. I. Å.	Remarks.	
		0 ¹	0 ²			0 ¹	0 ²
1δ	2061·0			0	2624·6		
1δ	62·5			0	29·3		
1δ	66·4			1	48·1		
4	66·8			00?	52·1		
1δ	68·3			0	59·3		
0δ	2217·1			0	63·3		
1	36·8			0	66·2		
0	43·9			0?	84·2		
0	84·6			00	2709·4		
9	98·8			0	10·7		
00	2309·1			0	12·5		
0	37·6			00?	23·3		
2	56·2			0	24·9		
1	65·8			00?	26·8		
0δ	80·3			00	28·2		
6	2452·8			00	29·8		
0	58·5			0δ	43·5		
1	67·9			3δ	68·6		
0	68·6			0δ	87·2		
2δ	70·1			00	2806·4		
0δ	73·2			00	3109·1		
2	75·5			0	11·1		
1	95·6			1	20·6		
3	2502·3			1	21·4		
00	13·6			0	3349·3		
8	31·6			2	55·4		
2δ	38·9			0	3425·2		
1δ	40·4			1	26·5		
1δ	48·2			3	57·6		
00?	50·7			1	3520·6		
00?	51·8			0	34·4		
1δ	58·2	d?		00	3753·3		
00?	81·2			0	77·3		
1	84·5			0	3908·4	0 ¹ of 977·02?	
00?	2604·3			0	4087·5		
00?	05·2			1	4111·2		
00?	07·2			0δ	35·7		
00	12·2			00	45·4		
0	13·0			1	4204·4	} 0 ³ of 1401·15?	
0	14·3			1	05·4		
1	18·1			3	72·0	0 ¹ of 1068·0?	
2δ	20·5						

Wave-lengths (λ air I. Å) from the plate taken with Anderson's apparatus.
(Iron comparison spectrum.)

Int.	λ air. I. Å.	Remarks.	Int.	λ air. I. Å.	Remarks.
4	2296·89	C	6·89	6·89	
5	98·09		8·10	8·08	
7	2452·00		2·01	1·99	
1	69·16				
1	71·13				
			1	2473·90	
			1	75·24	
			0	80·50	
			00	81·78	
			1	2504·33	

TABLE XII—Thallium (continued).

Int.	λ air. I. Å.	Remarks.	Int.	λ air. I. Å.	Remarks.
		0 ¹ 0 ²			0 ¹ 0 ²
0δ	2511·04		5	3112·35	2·34 2·35
4	12·78		5	13·43	3·44 3·43
0	26·10		4	47·68	7·69 7·67
7	30·88	0·91 0·86	4	53·30	{ 3·45 3·30
0	35·67				(not
0δ	40·72		4	53·61	resolved) 3·61
00	96·01		3	56·79	6·77 6·80
1	2611·09		6δ	60·94	0·97 0·93
0	27·59		4δ	61·40†	
0	56·79		3δ	63·53	3·53 3·51 3·54*
3	61·08	d. ?	3δ	86·61	6·63 6·60
			3	91·90	
			3	97·80	
		0 ¹ 0 ²	5	3201·37	1·38 1·37
00	80·41		4	07·40	7·41 7·39
1	2700·72		5	14·86	4·90 4·84
0	21·62		5	16·57	6·53 6·59
1δ	61·42		4	17·21†	
1δ	62·28		5	22·03†	
3δ	67·87		5	22·71†	
2	74·91	4·94 4·89	4δ	23·32†	
1	77·86		5	33·63†	
0δ	81·26		6	39·64†	
2	2814·43		6	40·55†	
2	15·10		5	49·02	9·03 9·02
2	33·80		5	73·47	3·50 3·45
1	39·18		4δ	95·05	5·08 5·04
1	41·02		5	3300·80	0·81 0·79
1	41·88		4	23·51	3·50 3·52
2	48·11		4	27·00	6·99 7·00
1	62·68		4	30·64	0·69 0·61
1	77·74		4	39·56†	
1	80·68		4	43·83†	
5	92·75	2·73 2·76	4	47·65†	
4	99·45		5	48·48	8·49 8·47
5	2908·48	8·49 8·48	4	56·82†	
6	16·00	6·01 6·00	4	73·38†	
5	30·66	0·67 0·65	4	81·11	1·14 1·10
3	71·58	1·58 1·58	3	81·71	1·72 1·71
3	73·64	3·63 3·65	4	83·68	3·66 3·69
3	99·30	9·31 9·30	4	3403·32†	
3	3000·38	0·40 0·36	4	19·37†	
4δ	02·44		5δ	47·13†	
4	05·07	5·07 5·07	6	54·04†	
5	21·04	1·04 1·04	10	56·34	6·36 6·32 6·35*
3δ	28·54		5	58·61†	
3δ	29·95		4	60·89†	
3δ	31·55		4	66·53	6·54 6·52
5	76·27	6·24 6·28	5δ	94·08	4·12 4·06
3	84·16	4·13 4·17	9δ	3507·41	7·44 7·40
3	87·49	7·47 7·50	5δ	11·00†	
4	88·06	8·09 8·04	8δ	13·39	3·39 3·36 3·39*
4	89·49	9·48 9·50	5	15·67†	
7δ	91·61	1·64 1·58 1·61*	7δ	19·24	9·21 9·26 9·24*
4	3105·48	5·53 5·46	5	29·44	9·45 9·44 9·43*
5	06·94	6·91 6·95	5	55·01	5·02 5·01

TABLE XII—Thallium (continued).

Int.	λ air. I. Å.	Remarks.		Int.	λ air. I. Å.	Remarks.	
		0 ¹	0 ²			0 ¹	0 ²
5	3557.56	7.56	7.56	7	4380.57	0.58 (A),	0.56 (B)
5	92.08†			5	4414.91		
7	3601.70	1.71	1.69	4	16.94		
7	06.29	6.24	6.32	5δδ	79.86	} very diffused.	
6	12.37			5δδ	89.01		
6	26.55			5δ	4512.66		
6	57.16			6δ	29.32		
4δ	67.51			4	90.97	0.97 (A),	0.96 (B)
5	70.39			4	4638.90		
9δ	75.12	5.10	5.12*	5	41.85		
6	83.52			6	49.22		
7	3775.72	5.72	5.72*	6	61.65		
6	3848.58			4	76.25		
10	3933.05	3.00	3.07*	3δ	96.07		
5	44.26			4δ	99.21		
6	46.02			4δ	4705.44		
5	4000.03			10δ	37.32		
3	02.61			3	65.71		
4δ	04.91			4	65.86		
6	08.38	8.36 (A),	8.40 (B)	7	4808.20		
5	19.84	9.79 (A),	9.88 (B)	6δ	35.95		
4	42.87	2.85 (A),	2.89 (B)	8	91.95		
5δ	69.76			8δ	4981.60		
5	72.18			7δ	5078.94		
5	75.87			6δ	86.99		
6δδ	96.24	} very diffused.		6δ	5152.48		
6δδ	99.69				2δ	5321.97	0 ² of 2660.99 ?
10	4109.85	9.87 (A),	9.83 (B)	5	62.40		
10	55.75	5.76 (A),	5.73 (B)	4	5535.67	Ba	Reversed
7	72.92	2.94 (A),	2.90 (B)				
4	85.46						
4δ	89.83						
4δ	98.77						
4	4214.58						
4δ	34.93						
5	66.44						
10	69.81	Ba ? 9.81 (A),	9.81 (B) 9.81*				
6	83.26	3.26 (A),	3.26 (B)				
4	4333.32						
5	38.69						
5	49.47						
4	51.29						
4	66.89						
5δ	69.98						

* These are wave-lengths determined by aid of the 15-foot concave grating of the Mount Wilson Observatory.

† These are inferred first order wave-lengths from lines actually found only in the second order spectrum. The shortest wave-length involved is $2 \times 3161.4 = 6323$ app. The films used were quite insensitive to light of this or longer wave-lengths, indeed no lines between λ 5550 and λ 6323 were first order lines, so that the inference that these lines are in their 2nd order positions is justified.

N.B.—Only the strong lines are recorded of wave-length > 2900 .

TABLE XIII—Germanium.

Int.	λ vac.		Remarks.		Int.	λ vac.		Remarks.	
	I. Å.					I. Å.		0 ¹	0 ²
3	599.61	○	9.62	9.61	2	923.3			
2	609.73	○?	9.70	9.75	0	26.8			
2	29.71	○	9.63	9.76	2	30.6			
3	44.15	○	4.17	4.14	9	36.7			
3	702.32	○	2.32	2.32	6	38.9			
4	02.87	○	2.88	2.86	2	42.7			
48	03.88	○	3.95	3.85	2	43.9			
58	18.53	○	8.56	8.52	0	46.5			
1	46.7		6.72	6.99?	0?	50.5			
1	58.5				0?	51.9			
0	59.48		9.55	9.45	3	53.2			
38	60.3		0.25	0.09, 0.44 double	0?	55.7			
					0?	57.0			
					0	57.6			
			0 ¹	0 ²	3	58.4			
0	61.10		1.11	1.09	0	63.5			
2	62.02		2.01	2.02	2	65.4			
0	67.9				6	71.3			
0	71.9		1.80	1.97	7	76.9			C?
0	72.92		2.95	2.91	1	80.6			
1	74.49		4.50	4.49	4	84.8			
4	79.86	○	9.77	9.91	5	87.5			
6	87.73	○	7.73	7.73	5	87.9			
6	90.18	○	0.23	0.16	6	89.0			
5	96.66	○	6.65	6.66	5	90.5			
0	802.2				0	91.5			
0	08.3				4	92.2			
5	32.9	○			8	95.7			
5	33.3	○○		p.	8	96.5			
5	33.7	○○		p.	1	98.9			
6	34.5	○○			0	99.3			
6	35.3	○			6	1004.2			
5	47.8				1	05.2			
0	50.0				0	08.0			
0	51.6				9	11.2			
0	56.9				6	12.3			
0	66.3				1	13.1			
6	68.3				0	15.3			
0	71.0				88	16.5			
0	71.8				0	17.4			
0	77.8				0	21.8			
0?	79.1				0	24.4			
0	80.4				0	25.5			
0	89.2				18	28.0			
5	92.6				5	29.3			
3	98.9				0	31.0			
38	904.1				0	31.8			
1	06.7				4	32.6			
0?	10.5				3	33.4			
0	13.0				0	34.6			
8	15.0				0	36.2			
0?	16.0	N?	(916.13)		0	36.8			
0?	16.8	N?	(916.82)		4	38.3			
0	18.9				5	40.8			
0	20.5				4	42.1			
0	21.5				7	45.5			

p.

TABLE XIII--Germanium (continued).

Int.	λ vac. I. Å.	Remarks.		Int.	λ vac. I. Å.	Remarks.	
		0 ¹	0 ²			0 ¹	0 ²
0	1048.6			0	1179.0		
5	49.9			8	83.4		
0	51.7			12	89.0		
4	54.5			0	94.7		
0	58.1			0	95.6		
6	58.9			4	1206.5		
1	63.0			0	12.5		
1	65.9			58	15.7		d ?
1	66.6			0	16.6		
5	68.3			0	21.4		
5	69.1			0	22.4		
6	72.5			0	25.9		
0	74.8			12	29.8		
0	76.7			0	34.2		
0	77.9			6	37.1		
0	84.5	N ?		0 ?	47.47	C	
5	85.4	N ? ?		0	49.2		
5	86.5			0	50.2		
1	87.7			1	51.5		
8	88.3			6	61.9		
5	89.4			4	64.8		
5	92.0			0 ?	66.2		
0	97.1			1	94.6		
0	97.9			0	96.7		
5	98.6			3	99.0		
3	1104.1			0	1301.0		
6	05.0			1	02.2		
1	08.2			0	03.0		
1	09.1			0	03.2		
1	09.8			1	04.8		
0	10.6			0	06.1		
18	16.6			0	14.4		
6	16.8			0	15.3		
2	20.3			0 ?	33.2		
1	22.0			3	34.57	C	(1334.54)
1	22.4			4	35.63	C	(1335.72)
0	25.3			1	38.7		
3	28.2			3	43.6		
0 ?	31.1			0 ?	46.0		
8	38.0			28	52.9		
0	39.0			4	62.5		
0	49.7			2	71.3		
8	50.6			0	73.2		
0	52.1			6	79.69	Al	(1379.8)
1	53.7			7	84.20	Al	(1384.16)
7	59.1			0	91.6		
8	59.7			0	92.6		
8	60.9			8	93.8		
0	63.3			5	95.6		
4	64.2			0	1401.4		
0	65.3			6	02.8		
0 ?	73.6			0	14.8		
6	73.8			0	17.2		
0	74.9			0	20.2		
18	75.8			0	48.3		
0	76.3			1	94.0		0 ² of 747.0 ?

TABLE XIII—Germanium (continued).

Int.	λ vac. I. Å.	Remarks.	Int.	λ vac. I. Å.	Remarks.	
					0 ¹	0 ²
6	1494.9	N ?	2	1540.0		
0	97.6		0	43.9		0 ² of 771.95 ?
0	99.2		5	48.22	C	(1548.26)
6	1500.6		4	50.87	C	(1550.84)
0 ?	11.6		0	58.8		
1	17.4		0	60.8	C ?	
0	21.6		1	61.5	C ?	
0	23.2		4δ	77.0		
0	24.4		0	81.2		
3	25.3		6	1600.0		
2	27.0		7	02.6		
0	33.3		8	05.88	Al	(1605.83)
0	36.1		10	11.95	Al	(1611.93)
2	38.2		3δ	24.1		

TABLE XIV—Tin.

Int.	λ vac. I. Å.	Remarks.	Int.	λ vac. I. Å.	Remarks.	
					0 ¹	0 ²
3	1302.2	Wave lengths by Bloch (‘Comptes Rendus,’ T. 177, p. 1025, 1923).	10	1437.7	1437.7	
4	06.0		4	49.9	50.1	
12	14.7	1315.8	6	75.1	75.1	
7	27.5	27.0	3δ	89.2	89.7	
3	34.7	34.5	4	1570.4	1570.2	
2	46.1	46.1	2	74.3	74.3	
4	47.8	47.7	4	1699.0	1699.0	
1	55.6		15	1757.1		
3	69.7	69.9	20	1810.7		
5	87.0	86.9	8	30.7		
7	1400.7	1400.7	20	98.8		
5	10.8	10.8	5	1907.6		
			5	41.7		

THE HEAVIER ELEMENTS, AND SERIES CLASSIFICATION, ETC.

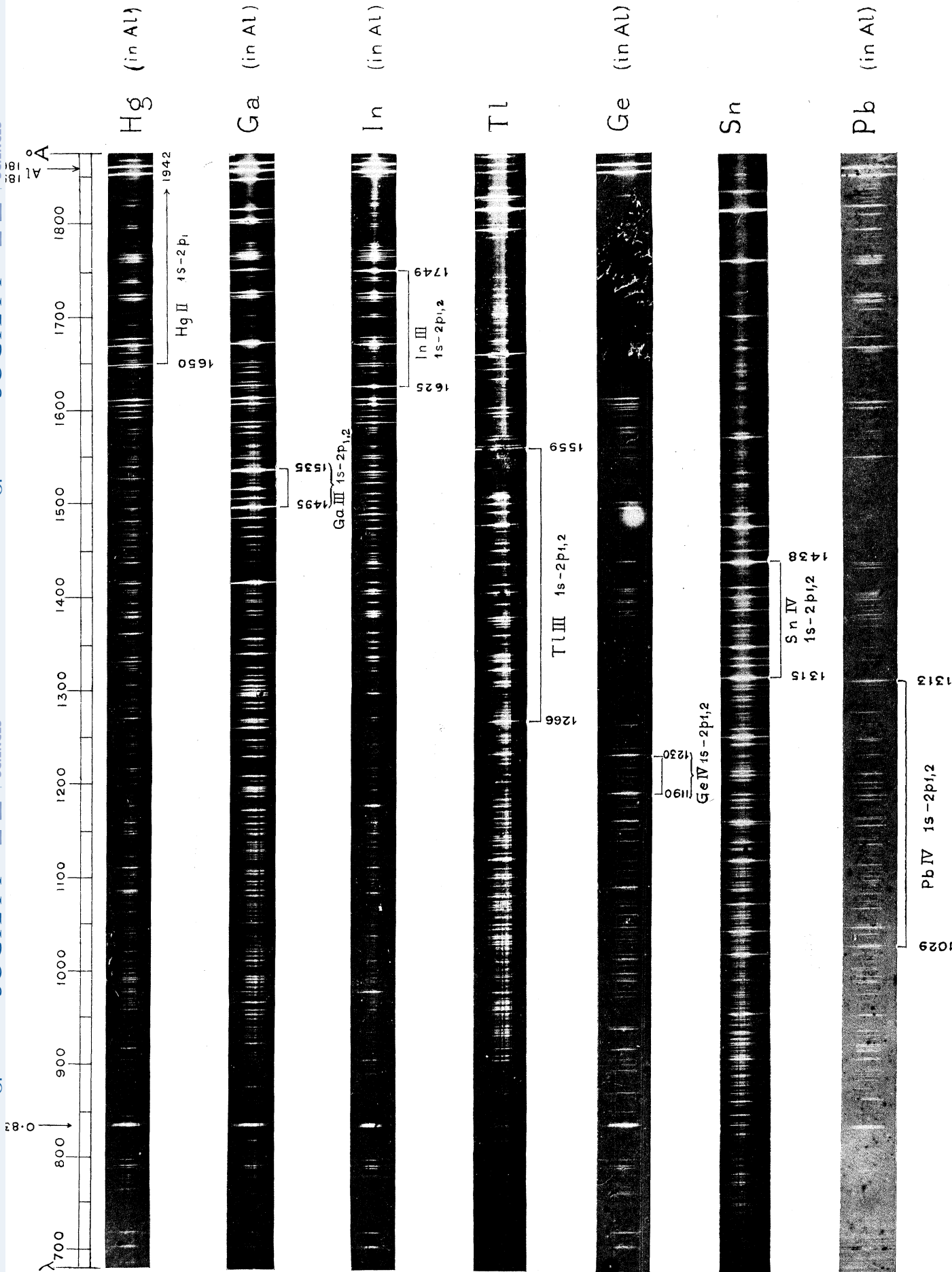
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TABLE XV—Lead.

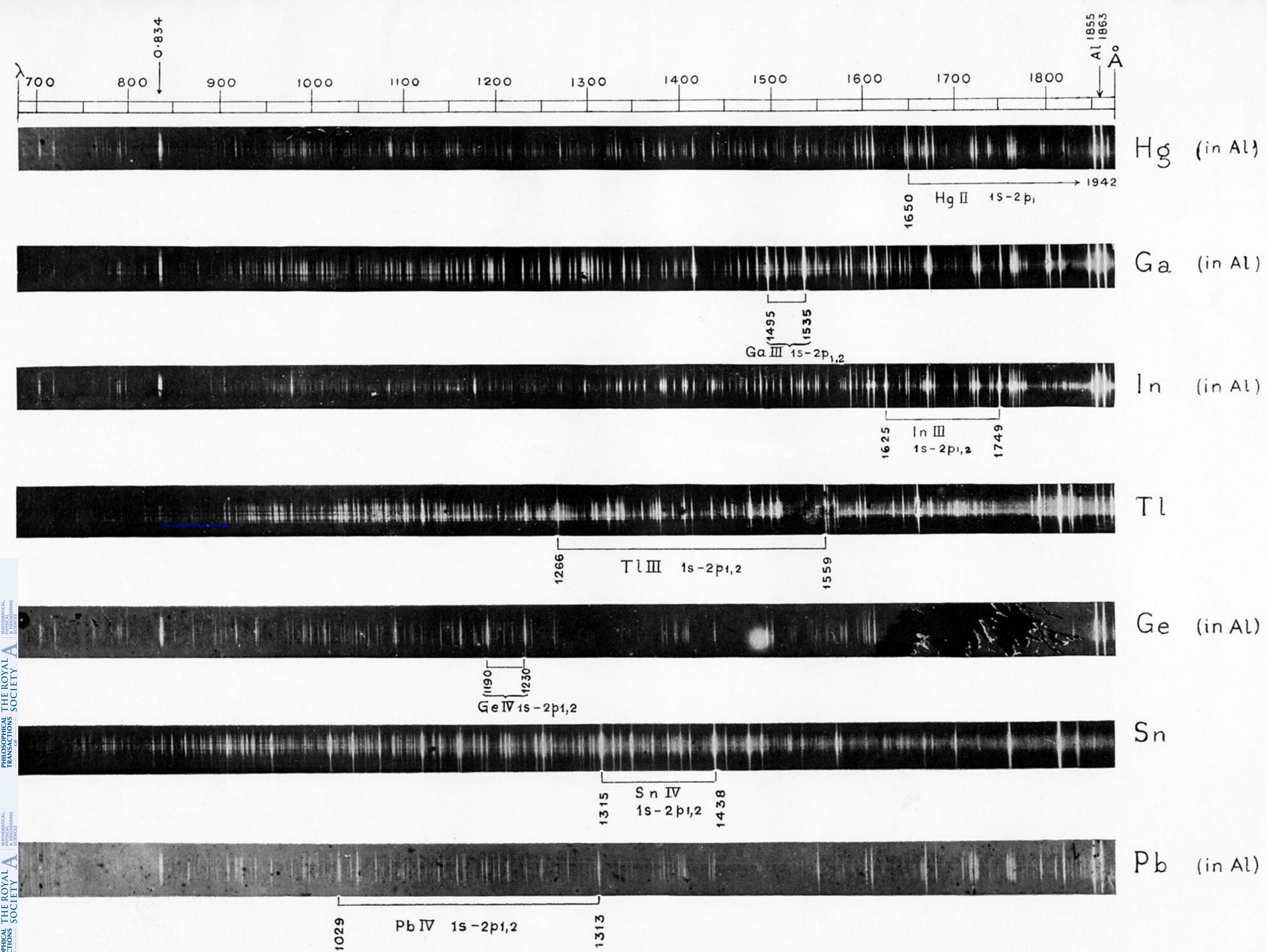
Int.	λ vac. I. Å.	Remarks.		Int.	λ vac. I. Å.	Remarks.	
		0 ¹	0 ²			0 ¹	0 ²
0	767.5			00	1021.4		
1	86.48			00	22.2		
2	87.73	O	6.49 6.48	10	28.7		
3	90.21	O	0.20 0.21	3	30.5		
0	96.58	O	6.57 6.58	3δ	41.3		
1	802.07		2.10 2.06	12	48.9		
00 ?	04.8			0	51.4		
00 ?	06.3			2	52.3		
1	15.91		5.95 5.89	0	60.6		
0	19.5			1δ	62.8		
0	26.9		6.95 6.83 ?	00	68.0		
0	27.8		7.87 7.74	4	69.2		
0	29.32		9.32 9.32	1	72.1		
0	30.3			1	73.1		
		O	834 group of O incompletely resolved.	3	74.7		
		O			3	76.8	
3	34.5			0	80.8		
3	35.4			1	83.91	N	(1084.04)
00	49.6			2	84.65	N	(1084.60)
00	52.1			3	85.69	N	(1085.67)
00 ?	54.9			1	87.6		
0	57.8			2	88.9		
0	62.5			0	90.1		
5	64.0			00	94.3		
3	70.5			1δ	96.5		
4	83.9			0δ	98.4		
1	85.0			1δ	99.2		
3	88.5			0δ	1103.6		
4	90.8			00	04.8		
4	94.4			00	05.6		
3	903.6			1	08.7		
7	06.7			2	15.0		
0	08.5			4	16.2		
3	15.9			0	17.4		
0	16.8			00 ?	18.9		
1δ	18.1			00	19.9		
3	20.4			3	23.7		
4	22.5			00	31.9		
1	23.4			2	33.2		
0	24.5			5δ	37.8		d ?
3	27.7			1	42.9		
3	32.3			3	45.0		
0δ	33.7			0	48.3		
2δ	37.2			8	58.0		
00 ?	44.6			4	65.1		
00 ?	46.4			4	67.0		
5	54.4			00	76.0	C ?	
00 ?	55.5			6	85.6		
0 ?	70.3			7	90.1		
4	77.0	C	(977.02 ?)	2	97.8		
0	81.2			0	99.5		
2	89.90	N	(989.90)	3	1203.6		
3	91.65	N	(991.66)	0	06.6		
2	95.8			5	13.4		
1	1005.5			2	15.8		
00	12.5			1	31.3		

TABLE XV—Lead (continued).

Int.	λ vac. I. Å.	Remarks.		Int.	λ vac. I. Å.	Remarks.	
		0 ¹	0 ²			0 ¹	0 ²
3	1233.6			0	1623.9		p.
2	48.6			00	35.7		p.
4	50.6			00	38.5		p.
1	66.9			0δ	50.0		
0	74.6			00 ?	57.3		
3	79.5			00	60.1		d. ?
0	96.5			0	65.40	O	0 ² of 832.70
1	1302.4			0	66.45	O	0 ² of 833.23
00	04.9			0	67.48	O	0 ² of 833.74
00	06.1			0	68.87	O	0 ² of 834.44
2	08.2					O	0 ² of 835.22 is present as a close companion to 1671.1
9	13.2						
00	34.6	C ?					
1	35.6	C ?	d ?	9	71.1	Al ?	(1670.83)
0	43.1			5	82.2		
2	49.0			00	1700.3		
00	52.9			4	11.1		
0	62.6			00	15.2		
3	71.8			00	18.5		
00	73.4			3	19.43	Al	(1719.50)
3	79.77	Al	(1379.8)	4	21.47	Al	(1721.28)
5	84.20	Al	(1384.16)	5	25.01	Al	(1725.01)
1	89.0			3	26.5		
2	93.8			3	27.5		
3	1400.4			0	40.5		
1	02.9			00δ	49.9		
0	04.6			4	60.08	Al	(1760.12)
0	05.8			4	61.94	Al	(1761.96)
2	06.6			5	63.93	Al	(1763.95)
1	07.8			3	65.80	Al	(1765.81)
3	33.9			4	67.67	Al	(1767.75)
1δ	37.1			00	76.3		
2	39.32			00	81.0		
00	92.72	N	(1492.83)	1	88.3		
00	94.75	N	(1494.78)	0	91.7		
00	96.8			4δ	96.6		
00	98.9			2	1812.6		
00	1500.4			00	16.4		
00	01.8			6	22.1		
00	12.2			0	26.2		
00	34.8			0	30.8		
0	35.7			00	35.6		
2	48.22	C	(1548.26)	1	40.0		
0	50.74	C	(1550.84)	0	44.2		
20	53.1			20	54.91	Al	(1854.7)
0	61.4			20	62.93	Al	(1862.9)
0	64.4			0	73.3		
0	97.8			1	1931.9		
7	1605.86	Al	(1605.83)	4	36.6		
9	11.94	Al	(1611.93)				



The plate shows the spectra obtained on Schumann plates over the region λ 700 Å U to λ 1900 Å U. The scale is about three times that of the original negatives. The positions of the lines 1s-2p_{1,2} are indicated in each of the spectra.



The plate shows the spectra obtained on Schumann plates over the region λ 700 Å U to λ 1900 Å U. The scale is about three times that of the original negatives. The positions of the lines $1s-2p_{1,2}$ are indicated in each of the spectra.

