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ON THE SPARK SPECTRA OF LEAD

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The spectrum of Lead has been the object of many investigations. Yet until recently little progress has been made in the identification of series relationships in the arc and spark spectra of the element. This element is the chemical analogue of C, Si, Ge and Sn ; and since it has the same number and type of outer electrons its spectral structures may be expected, according to present-day theories, to resemble those of the abovementioned elements. Such resemblances between homologous spectra are often very close, though there are occasionally minor but significant differences, which may perhaps prove of importance in the refinement of modern atomic theories. Recently through the work of Thorsen[1], Grotrian[2], Sur[3] and McLennan[4], a distinct advance was made in the analysis of the arc spectrum of Lead. The first spark spectrum of the element was investigated by Geissler.[5]

The preliminary attempts at the classifications of the second and third spark spectra of Lead, from the existing lists of published wavelengths was seriously handicapped by the lack of descriptive data. Descriptions of arc and spark spectra of the element in limited wavelength intervals have been published by various observers. The most reliable ones up to the year 1911 are quoted by Kayser in Volume VI of the Handbuch der Spectroscopie. They are by Kayser and Runge[6] (arc spectrum 2085 to 6002-A.U.), by Thalen[7] (spark spectrum 4058 to 6656 A.U.), by Exner and Haschek[8] (arc spectrum 2237 to 6002 A.U., and spark spectrum 2170 to 4572 A.U.), and by Eder and Valenta[9] (arc spectrum 5609 to 7229 A.U., and spark spectrum 4272 to 6793 and 2088 to 2733 A.U.). Since the appearance of this work in 1912 the spectrum of this element has been reinvestigated by Klein[10], with greater accuracy by using a 20 feet concave Grating Spectro graph. All the abovementioned measures were based on Rowland's system of standard wavelengths. In addition to these, contributions to the spectra of Lead have been made by Kimura and Nikumura[11], who, by photographing the cathode spectrum grouped some of the important lines under successive stages. No attempts were made by these authors to measure the wavelengths accurately. Only after the present work was begun was the writer able to procure a paper published by S. Smith[12], who photographed by means of a two-metre concave grating, the vacuum spark between electrodes of the metal, in the region 2400 A to 4800 A. It is found however that the hot spark does not give the highest members of spark lines, which I have been able to photograph with the highest excitation in the condensed spark. This is clearly seen from an examination of the writer's spectrograms (plates II and IV).

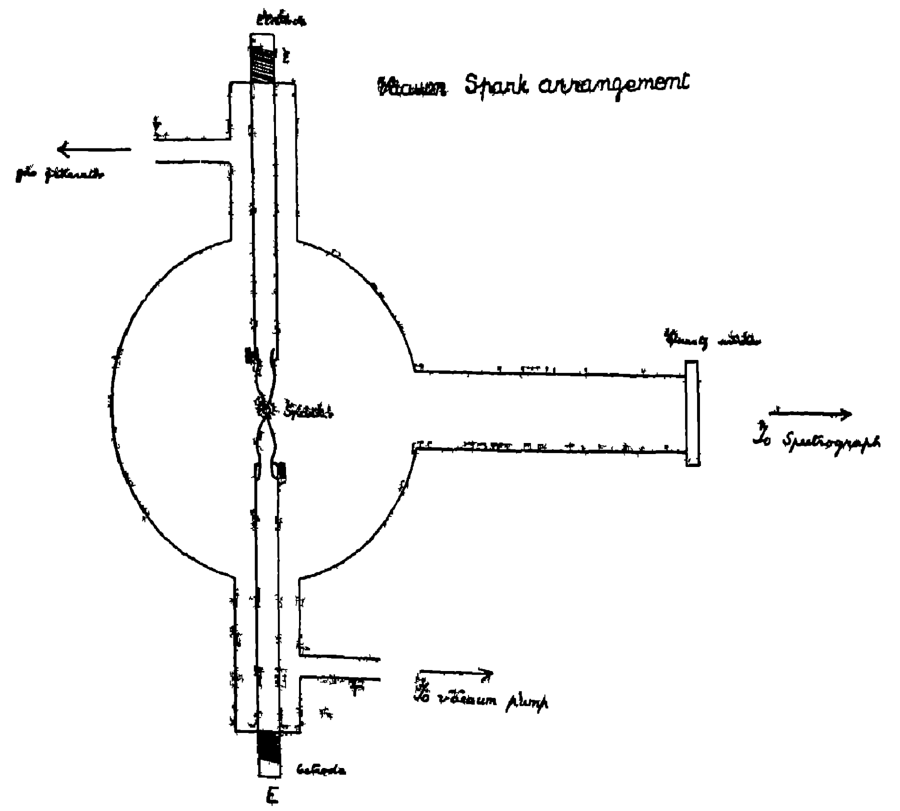
The measurements till now available are not sufficient for a complete analysis of the spark spectrum of Lead, since it is desirable to know the degrees of excitation at which the various lines appear and also to know the character of the spectrum lines, i.e., their sharpness, diffuseness, etc. The experiments of the writer were therefore aimed at photographing the whole region 2050 to 7000 A, with higher dispersion and under different degrees of excitation as a preliminary to the analysis of the higher spark spectra The results show that the procedure is justified many additional lines having been discovered in this work The new observations of the spark spectrum together with the lines which have been classified in the spectra of Pb III and Pb IV are presented in this paper In addition to the accurate measurement of wave-lengths attempts have been made in this investigation to improve upon the earlier descriptions by making a careful selection of the lines characterising Pb I Pb II Pb III and Pb IV This critical differentiation of lines belonging to different stages is generally made by photographing the spectrum under varying degrees of discharge

To provide data likely to be useful in identifying the spectra of higher stages of ionisation a study was made of the spark spectrum of pure Lead in air in vacuo and in an atmosphere of hydrogen at varying pressures and also of the arc in vacuum between electrodes of the pure metal The spark was produced by a ½ kilo watt 20000 volt transformer The secondary contained a battery of large plate condensers of capacity 0 03 m f d (constructed for the purpose) in parallel with the spark gap in the experimental chamber To distinguish lines due to different stages of ionisation the spectrum was photographed under varying degrees of discharge which is done by including in the secondary circuit a variable self inductance and capacity

Description of apparatus

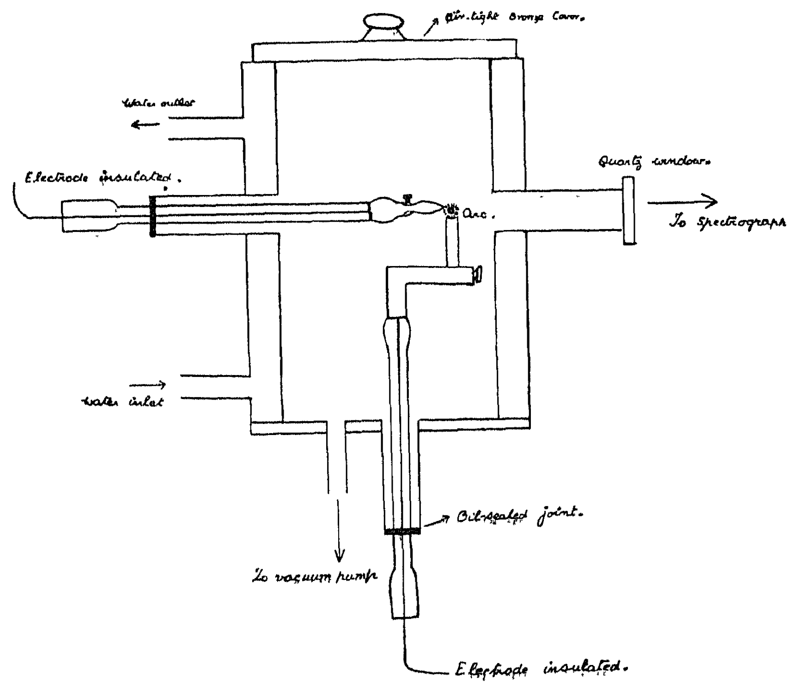
Sources of radiation—The apparatus used for the study of the spark spectrum is shown in diagram I It consists of a pyrex bulb capacity about one litre with side openings EI through which the electrodes pass To the ends of these small pieces of metal can be fixed A plane plat of quartz is attached to the end of the long projecting tube and serves as a window through which the spectrum of the spark is photographed. The two side tubulures (TT) are intended for filling the flask with hydrogen Pure hydrogen gas from a generator after passing through drying agents is passed through the flask for nearly 30 minutes, thereby driving the last traces of air from the flask By connecting the flask then to an air pump the flask could be exhausted to any desired pressure and the spark spectrum photographed

FIG 1



The spectrum of the vacuum arc of the metal was photographed, using a specially constructed arc lamp as the source of radiation. A diagrammatic sketch of the vacuum arc is given to Figure II. It consists of a double-walled cylindrical vessel fitted with a vacuum joint for one electrode and an aperture opposite for light to emerge. The second electrode passes through a similar joint in the base of the lamp and the clip for the specimen is arranged so that the arc is struck as close as possible to the window, without arcing to the wall taking place. The lid of the vacuum chamber is a bronze disc, which has been ground to make a tight joint which can be sealed with suitable vacuum wax or grease. Connection to the vacuum pump is made through the base of the lamp and nozzles are provided so that the cylindrical wall may be kept cool with circulating water. Each electrode consists of a brass tube passing through a gland and having an insulated wire passing through it. Electrical connection is made to the terminal situated on the ebonite handle, provided for the manipulation of the arc. The glands have been filled with vacuum grease for maintaining a vacuum. The lamp operates steadily with currents varying from 4 to 6 amps.

FIG. II.



Spectrographs employed.—The spectrograms were obtained in the first and second order of a 4-inch concave grating, of 10 feet radius of curvature in eagle mounting. These were supplemented by several plates taken with a Hilger E_2 Quartz spectrograph, which is used not only to record the faint lines in the ultra-violet, but also for wavelength measurements in the region 2550 to 2050-A. In this region this spectrograph compares favourably in dispersion and resolving power with the concave grating spectrograph and at the same time, has a good light gathering power. Comparison spectra of the iron arc are impressed on the plates after each of the exposures. The spectrograms are obtained on photographic plates of thin glass which could be bent to the focal curves of the spectrographs. The region 3600 to 6500-A was also visually examined, with a view to study the behaviour of the lines under different conditions of excitation, by a constant deviation spectrograph. For photographing the region below 2500-A, the plates were sensitized in the manner described in Volume II of Baly's Spectroscopy, with comptometer oil. The exposure times ranged, in the case of the concave grating spectrograph from 10 to 30 minutes, while in the case of the quartz spectrograph, up to 2500-A, the times ranged from 5 to 10 minutes and in the region 2500 to 2050-A exposures of 15 to 30 minutes were given.

1-A

Method of wavelength determination.—All plates were measured in two directions with a Hilger comparator and the wave length measurements were made relative to International Secondary Standards in the spectrum of the iron arc. For the region below 3370 A the iron arc wavelengths published by Burns were used. In the case of the prism spectrograms the wavelengths were calculated by means of Hartman's dispersion formula $\lambda=\lambda_0+\frac{c}{n-n_0}$ where λ_0, c and n_0 are constants determined from the comparison spectrum and n the distance of the unknown line from a fixed point of reference on the plate. Spectrograms obtained with the grating are measured by using a linear scale.

Intensity estimates were made directly from the plates as viewed in the measuring microscope on a scale of 0 to 10. The vacuum wave numbers corresponding to the observed wavelengths are taken from Kayser's Tabelle der Schwingungszahlen and are given in column 3 of Table I. In column 1 are given the observed wavelengths in I A. In column 2 are given the intensity estimates in column 4 the stages of ionisation of the prominent lines and in column 5 are given the lines classified in this investigation. The symbols accompanying the intensity values have the following meanings :-

s = sharp, d = diffuse, bd = broad and diffuse and dd = very diffuse.

TABLE I

Wavelength (I.A.)	Int	Wave number cm^{-1}	Stage and classification
655.82	3	152439	IV 6 D —7p P
760.90	0	131420	IV 6 D —7p P
804.55	1	124293	IV 6 D —7p P
884.98	6	112997	IV 6 D_3—7p P
908.54	5	110067	IV 1 P —2 S
922.5	4	108401	IV 1 P —1 D
979.47	2	102096	IV 6 D_3—7p D_2
995.8	2	100422	III 1 P —1 $^3\overline{P}$
1028.7	10	97210	IV 1 S —1 P
1030.5	3	97040	III 1 ^{3}P —1 D
1048.9	12	95338	III 1 S —1 P
1059.3	1	94400	IV 6 ^{2}D —7p ^{4}P
1069.2	2	93528	III 1 P —1 D
1074.7	3	93049	III 1 P —1 D
1087.34	2	91968	IV 6 D_2— 7p^1 P
1096.5	1d	91189	IV 6 D —7p D
1103.6	0d	90613	IV 6 D —6p D
1104.8	0d	90510	IV 6 D_3—6p F
1115.0	2	89686	III 1 ^{3}P —1 S
1116.2	4	89590	IV 1 ^{3}P —1 D
1118.6	3	89397	III 1 P —1 D
1123.45	3	89012	IV 1 P_2—2 S
1142.9	1	87497	III 1 P —1 $\overline{P}$
1145.0	3	87336	IV 1 P —1 D
1165.1	4	85830	III 1 P —1 $\overline{P}$
1167.0	4	85690	III 1 P —1 S
1231.3	1	81215	III 1 ^{3}P 1 $\overline{P}$
1233.6	3	81068	IV 6 D_2—7p D
1250.6	4	79962	III 1 P_2—1 D
1266.9	1	78933	III 1 P_2—1 ^{3}D
1274.6	0	78456	III 1 $^3P_2$- 1 ^{3}D
1279.5	3	78167	IV 6 D —6p F
1308.2	2	76441	IV 6s^1 D —6p^1 D
1313.2	9	76150	IV 1 ^{2}S —2 P
[illegible]	0	73381	IV 6s^1 $^3D_2$—7p^1 P
1371.8	3	72897	III 1 P_2—1 P
1406.5	2	71093	III 1^{3}P – 1 S
1437.1	1d	69585	IV 6s^1 D_2—6p D
1439.2	1d	69478	IV 6 D_2—6p F_3
1553.1	20	64387	III 1 S —1 P
1597.8	0	62586	III 1 P —1 D_2
1610.1	1	62107	III 1 P —1 D
1711.1	4	58442	III 1 P —1 D_2
1749.9	1	57146	IV 6 D_2—6p F
1826.2	0	54759	III 1 P —1 S
Th wrnt me sb gi her			
2060.43	3	48518.0	
2088.55	2	47864.8	I
2104.41	2dd	47504.1	
2107.73	5dd	47429.3	
2110.75	3	47361.5	
2114.98	1dd	47266.8	I
2132.21	3s	46884.8	
2142.83	5s	46652.5	
2152.64	4	46439.9	
2169.86	10bd	46071.4	
2174.61	0dd	45970.8	
2178.72	1s	45884.1	
2189.76	6	45652.8	I
2192.43	2	45597.2	
2203.62	8dd	45365.7	II
2218.21	3	45067.3	I
2237.48	8b	44679.2	I
2242.67	5	44575.8	
2246.83	10bd	44493.3	I
2254.13	3dd	44349.2	I
2259.76	0dd	44238.8	
2264.73	1s	44141.7	
2276.58	3s	43911.9	
2280.51	1s	43836.3	
2287.52	1bd	43702.0	
2290.17	0dd	43651.4	
2293.02	1bd	43597.1	
2294.16	0	43575.5	
2296.65	2	43528.2	
2300.35	4s	43458.2	IV 2 P —3^{2}S

TABLE I—*cont.*

Wavelength (I.A.)	Int.	Wave number in cm.$^{-1}$	Stage and classification.
2308·12	0bd	43312·7	
2312·70	0d	43226·2	
2317·45	2dd	43137·6	
2332·48	8bd	42859·7	I.
2343·72	1s	42654·1	
2353·91	0d	42469·5	
2360·19	1dd	42356·5	
2368·54	2d	42207·2	
2370·27	0s	42176·4	
2382·28	3s	41963·8	
2386·01	2s	41898·2	
2389·12	4s	41843·6	I.
2393·88	7dd	41760·5	
2399·76	3s	41658·1	
2402·16	7bd	41649·3	I.
2411·79	6bd	41450·4	I.
2416·13	0	41375·9	
2418·78	0	41330·6	
2424·21	0	41238·0	
2428·70	8bd	41161·8	IV $2^2P_1-2^2D_2$.
2433·65	2s	41078·1	
2443·91	10bd	40905·6	
2446·30	10bd	40865·7	I.
2463·21	2	40585·2	
2476·38	9	40369·3	
2478·63	3	40332·7	
2494·07	2d	40083·0	
2495·61	3d	40058·3	
2497·16	2s	40033·4	
2508·87	2	39846·6	
2527·06	3dd	39559·8	II.
2533·38	3dd	49461·1	IV.
2534·81	3dd	39438·8	IV.
2562·37	10	39014·7	III.
2568·48	6	38921·9	IV.
2577·34	8	38788·1	II.
2613·78	10	38247·4	
2614·28	5	38240·0	I.
2628·37	6	38035·1	I.
2637·81	3	37899·0	
2638·53	3	37888·6	II.
2640·51	3s	37860·2	
2650·33	6dd	37719·9	
2957·15	4s	37623·1	I.
2663·23	10	37537·2	I.
2697·60	5d	37059·0	
2712·81	0	36851·2	
2717·38	6d	36789·3	II.
2719·97	3d	36754·2	II.
2733·23	2	36575·9	I.
2734·58	2	36557·9	I.
2737·00	2	36525·6	I.
2740·87	2	36474·0	
2745·51	4	36412·4	
2752·15	1	36324·5	IV $2^2P_2-3^2S_1$.
2755·81	0	36276·3	
2802·00	10	35678·3	I.
2823·25	10	35409·8	I.
2833·12	10	35286·4	
2864·45	10	34900·5	IV $2^2P_2-2^2D_3$.
2868·19	3	34855·0	
2873·33	10	34792·6	I.
2937·55	4	34032·0	IV $2^2P_2-2^2D_2$.
2949·45	9dd	33894·7	II.
2977·98	9	33570·0	I.
3002·65	5s	33294·2	II.
3010·19	3s	33210·8	
3016·63	8dd	33139·0	II.
3025·55	2d	33042·3	
3028·77	2	33007·1	
3031·68	4s	32975·5	IV.
3043·90	10	32843·1	III $1^3D_1-1^3F_2$.
3052·64	10	32749·0	IV.
3056·84	4	32704·0	IV $1^2D_2-{}^2P_2$.
3062·42	4	32644·5	
3071·54	4	32547·5	
3087·13	5	32383·2	IV.
3089·17	7	32361·8	III $1^3D_2-1^3F_2$.
3103·00	4	32217·6	III.
3109·27	2	32152·6	
3118·17	5	32060·8	I.
3129·62	4	31943·5	III.
3137·87	10	31859·5	III $1^3D_2-1^3F_3$.
3145·70	4	31780·3	III.
3176·59	10	31471·2	III $1^3D_3-1^3F_4$.
3191·49	1	31324·3	III $1^3D_3-1^3F_2$.
3214·82	0	31097·0	
3221·00	10	31037·3	IV $2^2S_1-2^2P_2$.
3227·16	3	30978·1	IV.
3231·31	3	30938·3	
3240·21	9	30853·3	I.
3242·95	9	30827·3	III $2^3D_3-2^3F_3$.
3247·70	2	30782·2	
3262·41	3	30643·4	I.
3276·15	9	30514·9	III $2^3P_1-2^3D_2$.
3279·30	9	30485·6	III.
3280·09	9	30478·2	IV $1^3D_3-2^3P$.
3298·04	9	30313·3	III $2^3P_1-2^3D_1$.
3309·22	8d	30209·9	
3360·40	4s	29749·8	
3361·59	4s	29739·3	
3365·93	5s	29701·0	
3437·15	2s	29085·6	III.
3452·17	6d	28950·0	II.
3455·18	8d	28933·8	III.
3476·27	0	28758·3	
3483·46	9	28698·9	III $1^3F_3-1^3G_4$.
3505·37	3d	28519·5	III $1^3F_4-1^3G_5$.
3530·39	3	28317·4	
3534·06	3d	28288·0	
3560·75	6	28076·0	III $1^1D_2-1^1F_3$.
3563·06	4	28057·8	III $1^3F_4-1^3G_4$.
3565·26	1	28040·5	
3567·16	3	28025·5	III $1^1D_2-\beta$.
3572·79	10s	27981·4	
3586·29	5d	27876·0	
3589·81	7d	27848·7	III $1^3F_3-1^3G$.
3592·95	6s	27824·4	IV $2^2D_3-2^2F_3$.
3621·10	1s	27608·1	
3639·66	10s	27467·3	I.

TABLE I—*cont*

Wavelength (I A)	Int	Wave number in cm⁻¹	Stage and classification
3648 61	1bd	27400 1	
3655 56	8d	27347 8	III $1^3F_2—1^3G_3$
3665 64	0	27272 6	III
3671 48	10d	27229 3	I
3674·75	4	27205 0	III $1^3F_4—1^3G_3$
3683 57	10s	27139 9	
3689·22	8s	27098 2	III $1^3S_1—2^1P_1$
3699 52	0bd	27022 9	
3706 22	3d	26974 0	III $2^3P_0—2\,^3S_1$
3714 10	5dd	26916 8	II
3719 30	2dd	26879 2	
3729 06	4	26808 8	III $2^3P_1—2^3S_1$
3735 98	7	26759 2	
3740 13	10s	26729 5	
3749 22	1	26664 7	
3786 20	8d	26404 2	II
3827 66	8d	26118 2	III $2^1P_1—2\,^3D_2$
3832 94	10s	26082 3	III $2^3P_1—\alpha$
3841 83	10d	26021 9	III $2^3P_2—2^3D_3$
3854 11	10s	25939 0	III $1^3S_1—2^3P_2$
3873 22	1s	25811 0	IV
3909 29	5d	25572·9	IV $1^2D_2—2^1P_1$
3927 74	3b	25452 8	
3943 79	1ss	25349 2	
3952·11	8d	25295 8	III $1^3\bar{P}_0—2^3P_0$
3962·58	8s	25229 3	
3994 98	1s	25024 1	
4004 35	3s	24965 8	
4019 65	8s	24870 8	I
4031 48	3d	24797 8	
4041 51	1	24736 3	
4049 88	7s	24685 1	
4058 01	10dd	24635 8	I
4062 22	8s	24610·2	I
4077 51	2db	24517·9	
4095 04	2d	24412·9	
4128 84	2d	24216·0	III
4141 56	3b	24138 7	III $1^3\bar{P}_1—2^3P_2$
4153 99	3db	24066 5	
4168 05	7s	23985·3	I
4174 38	4s	23948 9	III $1^3D_2—1^3F_3$
4182 40	8s	23903·0	IV $2^2S_1—2^2P_1$
4242 50	3dd	23564 4	II
4245 47	10	23547·6	II
4272 64	8s	23398 2	III $1^1D_2—2^1P_1$
4386 89	10	22788·8	II
4400·95	6s	22716·0	III
4447 10	3d	22480·3	
4496 12	3s	22235·2	III $1^1D_2—2^3P_2$
4499 78	2	22217·8	
4534 54	3d	22046 8	
4571 45	7s	21868 8	III $2^3P_2—2^3S_1$
4605 28	3sd	21708 1	
4630 38	5s	21585 8	
4761 00	8s	20998 1	III $1^3S_1—2^3P_1$
4798 27	6s	20835 6	III $1^3S_1—2^3P_0$
4802 18	6s	20818 1	
4827 15	0	20710 4	III $2^1P_1—2^3S_1$
4855 20	1	20590 7	
4885 71	1	20462 2	
4941 12	1d	20232 7	
5003 59	3s	19980 1	III $2^1P_1—\alpha$
5005 68	6s	19971 8	
5043 21	10	19823 1	II
5062 91	3s	19746 0	III $1^3D_2—2^1P_1$
5066 24	3s	19733 0	
5117 31	2sd	19536 1	
5139 42	2s	19452 0	
5163 75	6s	19360 4	IV
5192 29	6s	19253 0	III $1^3D_1—2^1P_1$
5201 65	6s	19219 3	
5207 17	6d	19199 0	III $1^3\bar{P}_1—2^3P_1$
5220 42	2dd	19150 2	
5252 33	3d	19033 9	III $1^3\bar{P}_1—2^3P_0$
5274 51	4s	18953 8	IV
5372 65	10	18607 6	II
5471 80	1	18270 5	II
5496 61	1s	18188 0	
5523 50	5s	18099 4	III $1^3D_2—2^3P_2$
5544 60	1	18030 6	
5545 11	10	18028 9	II
5609 18	10	17823 0	II
5664 49	3s	17649 0	
5677 53	3s	17608 4	
5678 89	3s	17604 2	
5707 67	2s	17515 4	
5779 75	4s	17297 0	III $1^1D_2—2^3P_1$
5828 12	3sd	17153 4	
5857 59	6s	17067 1	III $1^3D_3—2^3P_2$
5876 65	7d	17011 8	II
5890 33	6s	16972 3	
5893 01	6s	16964 6	
5930 31	2s	16857·9	
5941 05	2s	16827 4	
6002 13	5s	16656 1	
6039 12	5s	16554 1	
6081 81	3dd	16437 9	II
6379 98	1	15669 7	
6660 15	8s	15010 5	II
6792 94	3s	14717 1	II

In addition to the spectrograms and wavelength measures obtained by the author, the wavelengths of Carrol and Mack have been used for the region 2100 A

Spectrum of Pb III

From the position of Pb in the table of elements it must be expected that the second spark spectrum consists of singlets and triplets and that the structure resembles generally that of the chemically analogous atom or ion C III, Si III, Ge III, and Sn III, Al II Ga II, In II and Tl II All these, except Pb III and ...

Pb IV, have already been analysed. The present work on Pb III, Pb IV, therefore completes our knowledge of the series regularities in the spark spectra of elements of the fourth group. According to the theory of spectra developed by Pauli-Heisenberg, Russel and Hund, the characteristic terms arising out of any electronic configuration can be predicted with certainty and it will be seen that the results of the analysis of these spark spectra are in complete agreement with the theoretical predictions. The structure diagram of doubly ionised Lead may be written in the following manner :—

TABLE II.

K			
2			
L_1	L_2		
2	6		
M_1	M_2	M_3	
2	6	10	
N_1	N_2	N_3	N_4
2	6	10	14
O_1	O_2	O_3	O_4 ...
2	6	10	
P_1	P_2	P_3 ...	
2			
Q_1	Q_2 ...		

There are two electrons outside the complete spectroscopically neutral shells, which alone are effective in producing the optical spectrum. The most stable structure is that in which the two valency electrons are in the P_1 level. The spectroscopic term corresponding to this configuration is $^1S_0$. Other less stable configurations and their characteristic terms are obtained by keeping one of the electrons in the P_1 orbit and allowing the other to run through the orbits P_2, Q_1, O_4, etc. The terms that these different electron configuration give rise to, may be predicted by the Hund Theory and are shown in the following table :—

TABLE III.

Electron configuration.	Terms predicted.	Terms observed.
2 P_1	1^1S_0	1^1S
$1P_1$ $1P_2$	1^3P, 1^1P	1^3P, 1^1P
$1P_1$ $1Q_1$	1^3S_1, 2^1S_0	1^3S, 2^1S
$1P_1$ $1O_4$	a^3F, a^1F	...
$1P_1$ $1P_3$	1^3D, 1^1D	1^3D, 1^1D
$1P_1$ $1Q_2$	2^3P, 2^1P	2^3P, 2^1P
$1P_1$ $1R_1$	2^3S_1, 2^1S_0	2^3S, 2^1S
$1P_1$ $1O_4$	1^3F, 1^1F	1^3F, 1^1F
$1P_1$ $1O_5$	1^3G, 1^1G	1^3G
$1P_1$ $1Q_3$	$2^3\underline{D}$, 2^1D	$2^3\underline{D}$, 2^1D
2 P_2	$1^3\overline{P}$, 1^1D, ^1S	$1^3\overline{P}$

The first clue to the identification of the triplet systems in Pb. III was the detection of the fundamental group 1^3D—1^3F, which should occur in the visible and quartz regions and which could be examined under different experimental conditions. Observations have also been made in the visible region with a prism spectroscope to find the intense triplet 1^3S_1—$2\,^3P_{012}$. The result is the identification of the prominent triplet given below :—

TABLE IV.

λ	Int.	ν	Δν
3854·05	12	25939·4	
			4941
4761·00	6	20998·1	
			163
4798·27	4	20835·0	

The choice of this is further supported by the detection of the member $1^3D_{23}—2^3P_2$ in the calculated region and by the identification of the triplet $2^3P—2^3S$ of the sharp secondary series The 2^3P separation (4941) is found to be in complete agreement with the value predicted from the relativistic doublet law

The first principal, sharp and diffuse series fall in the extreme ultraviolet which does not lend itself to careful examination of the lines Attempts were therefore made to fix by extrapolation and then to seek for confirmation by correlating the corresponding members of the spectra of corresponding elements A very valuable clue to the detection of these members is afforded by the application of the relativity laws to isoelectronic spectra of Hg-like atoms

An approximate idea of the 1^3P_{12} separation was obtained from the regular doublet sequence and from the relation that in the spectra of the same vertical group of the periodic table $\left(\frac{\Delta\nu}{Z^3}\right)$ is approximately constant These give for 1^3P_{12} a value of about 14000 and for 2^3P_{12}, a value between 4000 and 5000

The following table shows the regular doublet sequence for 1^3P_{12} and 2^3P_{12} separations and the value of $\left(\frac{\Delta\nu}{Z^3}\right)$ for elements of the same vertical group —

TABLE V —REGULAR DOUBLET SEQUENCE

	1^3P_{12} separation	$\sqrt[4]{\Delta\nu}$	2^3P_{12} separation	$\sqrt[4]{\Delta\nu}$
Hg I	4630 6	8 25	1545 6	6 27
Tl II	9339	9 83	2839	7 30
Pb III	14595	10 99	(4941)	8 40

TABLE VI —VARIATION OF $\Delta\nu/Z^3$

At No Z	Element	2^3P_{12}	$\Delta\nu/Z^3$	1^3P_{12}	$\Delta\nu/Z^3$
6	C III	12 8	356		
14	Si III	73 16	373	263	1 342
32	Ge III	459	448	1642	1 603
50	Sn III	1222 8	491	4031	1 613
82	Pb III	(4941)	60	14595	2 171

The application of the irregular doublet law to Hg like atoms indicated that the probable position of $1^3P_2—1^3S_1$ is at ν 70000 nearly In applying this sequence the method of Millikan and Bowen is adopted as shown below In the usual notation, the irregular doublet law may be written as follows —

$$\frac{\nu^1}{R}=\frac{(n_2^2-n_1^2)\,z^2-z\,(n_2^2\sigma_1\ \ n_1^2\sigma_2)+(n_2^2\sigma^2-n_1^2\sigma_2^2)}{n_1^2n_2^2}$$

When a line results from transition between orbits of two different total quantum numbers, (n_2 & n_1) we get from the above equation, by transposition

$$\nu^1=\nu-\frac{R\,(Z-A)^2\,(n_2^2-n_1^2)}{n_1^2n_2^2}=C^1Z+D^1$$

The expression on the left varies therefore linearly with the atomic number Z, for any given set of values n_2 & n_1 In the case of $1^3P_2—1^3S_1$ of Hg like atoms $n_1=6$, $n_2=7$ and $A=79$ The progressive variation of with atomic numbers is shown in the following table —

TABLE VII

At No. Z	Element	$\nu\ (1^3P_2-\nu\,^3S_1)$	$\nu^1=\nu-808\ 3\ (Z\ A)^2$	Difference
80	Hg. I	20782	19974	
81	Tl II	43501	40268	20294
82	Pb III	(71093)	63818	22550

Attempts have also been made, by the application of the Mosley law to the spectra of Ge III & Sn III and to the spectra of Hg-like atoms, to fix the approximate position of this triplet as a check on the irregular doublet sequence. A careful search was then made for the possible triplet $1\ ^3P_{012}$—$1\ ^3S_1$ among Caroll's [18] measures, below 1450 A, having in view the relative order and magnitude of intensities and the probable ratio of intervals between the lines, with the result that the following triplet was fixed.

TABLE VIII.

λ	Int.	ν	Combination.	
1406·6	2	71093	$1\ ^3P_2$—$1\ ^3S_1$	14595
1167·0	4	85690	$1\ P_1$—$1\ S_1$	3994
1115·0	2	89686	$1\ P_0$—$1\ S_1$	

Evidence for the possibility of this being the triplet in question is sought by searching for the complete six-line multiplet (diffuse) $1\ ^3P$—$1\ ^3D$.

The triplet $2\ ^3P_2$—$2\ ^3S_1$ being fixed in the case of Pb III, attempts have been made by the application of the irregular doublet sequence to locate the corresponding triplet in the case of Tl II, which has not been identified. In this case $n_2 = 8$, $n_1 = 7$ and $A = 79$.

$$\frac{R\ (n_2^2 - n_1^2)}{n_1^2\ n_2^2} = 584{\cdot}61.$$

The sequence is—

Z	Element.	ν.	$\nu^1 = \nu - 524{\cdot}6\ (Z\text{-}A)^2$.
80	Hg. I	2753·6	2229·0
81	Tl. II	...	[9690]
82	Pb. III	21868·8	17146·9

The interpolated value of ν^1 for Tl II is $\nu^1 = 9690\ (\pm 500)$.

$\therefore \nu = 9690 + 2097\ (\pm 500) = 11787\ (\pm 500)$, which is in the infra red, at about 8500-A.

A very interesting feature noticed in the spark spectrum of Lead is the partial inversion of the triplet F term, $1\ ^3F_{23}$ being negative. The location and identification of the complete six-line multiplet $1\ ^3F$—$1\ ^3G$, in approximately the calculated position is a strong evidence as to the correctness of the identification of the ^3F terms.

The singlet system of lines is generally the most difficult to work out. When this analysis was first undertaken not much progress could be made at first in the identification of the singlet spectrum. The strong line 1048·9 (12) was suggested as $1\ ^1S_0$—$1\ ^1P_1$ and 1553·1 (20) as $1\ ^1S_0$—$1\ ^3P_1$. While this work was in progress, the author's attention was drawn to a similar publication by Smith [14]. Although there is good agreement between the results of Smith and those of the author, there is disagreement in one or two important points. Smith has the following as $1\ ^3P$—$1\ ^3S$ and $1\ ^3P$—$1\ ^3P$.

TABLE IX.

	$1\ ^3P_2$.	$1\ ^3P_1$.	$1\ ^3P_0$.
$^3S_1$	76447 (15)	91047 (10)	95036 (7)
$^3P_0$	...	78157 (15)	
P_1	71095 (12)	85694 (15)	89687
$\bar{P}_2$	85833 (15)	100428 (10)	

It was pointed out in a note communicated to Nature [15] that evidently Smith had the author's $1\ ^3S_1$ as his $1\ ^3P_1$ and that $1\ ^3S_1$ suggested by the writer was further supported by the location and identification of the second series $1\ ^3S$—$2\ ^3P$, $1\ ^3D$—$2\ ^3P$ & $2\ ^3P$—$2\ ^3S$. The $1\ ^3P$—$1\ ^3S$ suggested by the author followed the irregular doublet law for the isoelectronic spectra of Hg-like atoms more closely. The author therefore suggested that an interchange of the two levels $1\ ^3S_1$ & $1\ ^3\bar{P}_1$ of Smith would bring the whole scheme into alignment. Attempts have also been made by the writer to identify the singlet spectrum, the results of which

3

have been published in a paper Smith[14] has since published another paper on the second spark spectrum of lead, in which the suggested modification was adopted There are still however two main points of disagreement between the classification of the writer and that of Smith The term $\nu = 101434$, classified by the author as 6s 6d $^1D_2$ is classified by Smith as 6s 7s $^1S_0$ Smith classified 1768 67 (56540) as $1\,^1P_1 - 1\,^1D_2$, while the writer classified 1711 1 (58442) as this combination It will be seen from the irregular doublet sequence shown below (Table X), that both $1\,^1P_1 - 1\,^1D_2$ and $1\,^1D_2 - 2\,^1P_1$ identified by the writer show a distinctly better progression than those of Smith Further the line $1\,^1P_1 - 1\,^1D_2$ should be a strong line It is found that most of these strong lines of the triplet and singlet systems are found in the wavelength measures of McLennan, Young and Ireton, Bloch and Lang But the line 1768 67 identified by Smith as $1\,^1P - 1\,^1D$ is not recorded by any of the previous investigators, while Carrol includes it as one of the lines belonging to Al These considerations indicate that the writer's classification and identification of $1\,^1D_2$ is more probable

TABLE X—IRREGULAR DOUBLET SEQUENCE

	$1\,^1S_0 - 1\,^3P_1$	$1\,^1S_0 - 1\,^1P_1$	$1\,^1P_1 - 1\,^1D_2$
Hg I	39413	54065	17265
Tl II	52390	75656	39501
Pb III	64387	95338	58442 – 56540

From the beginning of this investigation of the analysis of Pb III, it was felt that $^3P\,^3P$ group should be strong as in the case of the chemically analogous atoms or ions $1\,^1D_2$ and $2\,^1D_2$ terms of Smith are probably $1\,^3\bar{P}_1$ and $2\,^3\bar{P}_1$ On this supposition $^3P\,^3\bar{P}$ group and the resulting combinations have been identified by the author, thus supporting the validity of the writer's identification of $1\,^1D_2$ term The term values have been determined by assuming $1\,^3F_4 = 64\,800$, $\left(\frac{\nu}{9} = 7200\right)$ The resonance and ionisation potentials are 7 95 and 31 5 volts respectively, the largest term $1\,^1S_0 = 255216$ The details of the triplet and singlet systems identified in this investigation are given in the accompanying tables Table XV gives the configurations and term values for Tl II and Pb III and Table XVI gives other unclassified members of $^3P_{12}$ differences

TABLE XI

	$1\,^3P_2$ 176234		(14595)	$1\,^3P_1$ 190829		(3994)	$1\,^3P_0$ 194823	
$1\,^3S_1$	1406 6	(2)		1167 0	(4)		1115 0	(2)
105141	71093			85690			89686	
$1\,^3D_1$	1274 6	(0)		1074 7	(3)		1030 5	(3)
	78456			93049			97040	
$1\,^3D_2$	1266 9	(1)		1069 2	(4)			
	78933			93528				
$1\,^3D_3$	1250 6	(4)						
	79962							
$1\,^3\bar{P}_0$				1231 3	(1)			
109690				81215				
$1\,^3\bar{P}_1$	1371 8	(3)		1142 9	(1)			
103332	72897			87497			(91491)	
$1\,^3\bar{P}_2$	1165 1	(4)		995 8	(2)			
90407	85830			100422				

TABLE XII.

	2^3P_3 79202	4941	2^3P_1 84143	164	2^3P_0 84307
1^3S_1 105141	3854·11 25939 (10s)		4761·0 20998 (8s)		4798·27 20835 (6s)
2^3S_1 57334	4571·45 21868·8 (7s)		3729·06 26808·8 (4)		3706·22 26974 (3)
1^3D_3 96272	5857·59 (6) 17067·1 obs. 17070 cal.				
1^3D_2 97304	5523·5 (5) 18099·4 obs. 18102·0 cal.		Inf. red.		
1^3D_1 97785			Inf. red.		Inf. red.
$1^3\bar{P}_2$ 90407	Inf. red.		Inf. red.		
$1^3\bar{P}_1$ 103332	4141·56 24139 (3)		5207·17 19199 (6)		5252·33 19034 (3)
$1^3\bar{P}_0$ 109690			(25570)		3952·1 25296 (8)
2^3D_1 53827	3939·77 25375·0		3297·64 30316 (4)		3279·91 304799 (2)
2^3D_2 53628	3907·17 25573·7 (5)		3276·19 30514·5 (7)		
2^3D_3 53179	3841·6 26023·3 (7)				

TABLE XIII.

	1_3F_4 64800	(643)	1^3F_3 65443	(-502)	1^3F_2 64941
1^3D_3 96272	3176·59 31471·2 (10)		3242·95 30827·3 (9)		3191·49 31324·3 (1)
1^3D_2 97304			3137·87 31859 (10)		3089·17 32361·8 (7)
1^3D_1 97785					3043·9 32843·1 (10)
1^3G_5 36280	3505·37 28519·5 (3)				
1^3G_4 36742	3563·06 28057·8 (4)		3483·46 28698·9 (9)		
1^3G_3 37595	3674·75 27205 (4)		3589·81 27848·7 (7)		3655·56 27347·8 (8)

TABLE XIV.—SINGLET SYSTEMS.

Classification.	λ	Int.	ν Observed.	ν Calculated.
$1^1S_0—1^3P_1$	1553·1	20	64387	...
$1^1S_0—1^1P_1$	1048·9	12	95338	...
$1^1P_1—1^3S_1$	1826·2	0	54759	54737
$1^1P_1—1^3D_2$	1597·8	0	62586	62577
$1^1P_1—1^3D_1$	1610·1	1	62107	62103
$1^3S_1—2^1P_1$	3689·22	7	27098·2	...
$2^1P_1—2^3S_1$	4827·1	1	20710·4	20709
$2^1P_1—2^3D_2$	3827·66	8	26118·2	...
$1^3P_1—1^1D_2$	1118·6	3	89397	89393
$1^1P_1—1^1D_2$	1711·1	4	58442	...
$1^1D_2—2^1P_1$	4272·64	8	23398	23393
$1^1D_2—2^3P_2$	4496·12	3	22235	22234
$1^1D_2—2^3P_1$	5779·75	4	17297	17294
$1^3D_1—2^1P_1$	5192·29	4	19254	19260
$1^3D_2—2^1P_1$	5062·90	3	19746	19741
$1^1D_2—1^1F_3$	3560·75	6	28076	...
$1^3D_2—1^1F_3$	4174·38	4	23949	...
$2^3P_1—\alpha$	3832·94	10	26082	...
$2^1P_1—\alpha$	5003·59	3	19980	...
$1^3D_2—\beta$	4182·84	8	23903	...
$1^1D_2—\beta$	3567·16	3	28026	...

The term α above is probably 2^1D_2 term, while β is of the nature of an F term and is probably a^1F.

TABLE XV.—CONFIGURATIONS AND TERM VALUES FOR Tl. II & Pb. III.

Electron configuration.	Term.	Term values for Tl. II.	Term values for Pb. III.
$2\ P_1$	1^1S_0	164227	255216
$1P_11P_2$	1^3P_2	102499	176234
	$^3P_1$	111837	190829
	$^3P_0$	114784	194823
	1^1P_1	88565	159879
$1P_11P_3$	1^3D_1	47403	96272
	$^3D_2$	47797	97304
	$^3D_3$	48082	97785
	$^1D_2$	49064	101434
$1P_11Q_1$	1^3S_1	59008	105141
$1P_11R_1$	2^3S_1	...	57334
$1P_11Q_2$	2^3P_2	42199	79202
	$^3P_1$	44650	84143
	$^3P_0$	44866	84307
	2^1P_1	38020	78043
$1P_11Q_3$	2^3D_3	26023	53179
	$^3D_2$	26172	53628
	$^3D_1$	26300	53827
	2^1D_2	27333	58063
$1P_11P_4$	1^3F_4	(28000)	(64800)
	$^3F_3$	28114	65443
	$^3F_2$	28014	64941
	1^1F_3	...	73358
$1P_11P_5$	1^3G_5	...	36280
	$^3G_4$	...	36742
	$^3G_3$	...	37595

TABLE XVI.—OTHER UNCLASSIFIED MEMBERS OF Pb. III.

	1^3P_2	1^3P_1	1^3P_0
1.	1165·1 (10) 76447	995·8 (2) 91047	
2.	1073·1 (1) 93188	927·7 (3) 107794	894·4 (4) 111807
3.	1028·7 (10) 97210	894·4 (4) 111807	
4.	908·5 (0) 110072	802·07 124677	
5.	888·5 (3) 112549	786·48 (1) 127149	
6.	860·6 (0) 116200	764·57 (2) 130792	
7.	840·99 (5) 118908	749·09 (3) 133495	
8.	802·03 (5) 124684	718·07 (2) 139262	

Triplet number 7 is identified by Smith, recently as 1^3P-2^3S ; but the line 137491 classified by him as $1^3P_0-2^3S_1$ is not recorded either by Carroll or Mack.

Spectrum of Pb. IV.

The first successful attempt to find series regularities among the wavelengths of trebly—ionised spectrum of lead, was that made by Carroll[8], who identified the first members of the principal and diffuse series occurring in the vacuum grating region. In a recent communication[16], the present writer set forth the leading members of the secondary series, which may be expected in the region of longer wavelengths.

The term structure of the spectrum of Pb. IV is generally similar in character to that of any chemically analogous atom or ion. Of these the spectra of Au I, Hg II and Tl. III and those of Ge IV and Sn IV have already been analysed to some extent. We have in the atom of Pb. IV, a one electron system, which normally gives the simplest type of alkali-like doublet spectrum. As the electron runs successively through P_1, P_2, P_3, Q_1 . . . shells, the terms 1, ^2S, 1 ^2P, 1 ^2D, 2 ^2S, etc., are obtained, the largest term being 1 $^2S_1$. The more complicated scheme of doublets and quartets result, when one or more of the inner group of 10 O_3, electrons is excited. The terms which different electron configurations give rise to may be calculated according to the principles developed by Pauli, Heisenberg & Hund and are given in the following table. It will be seen from the table that corresponding to the addition of an electron to the three different states (^1S, ^3D, ^1D) of the Pb V core, three distinct families of terms arise.

TABLE XVII.

K L M N	O					P			Term prefix.	Terms predicted.	Series limit Pb V term.
$1_1 \ldots\ldots 4_4$	5_1	5_2	5_3	5_4	5_5	6_1	6_2	6_3			
60	2	6	10			(1)			6s	^2S	
60	2	6	10				(1)		6p	^2P	^1S
60	2	6	10					(1)	6d	^2D	
60	2	6	9			1(1)			$6s^1$	^2D	^3D
60	2	6	9			1	(1)		$6p^1$	^4P D F	
										^2P D F	^3D
										^2P D F^1	
60	2	6	9			1		(1)	$6d^1$	^4S P D F G	^3D
										^2S P D F G	
										^2S P D F G^1	^1D

The analysis of Cu I Zn II Au I & Hg II has shown that in addition to the regular doublet systems built on the d^{10} ion there is another important family of terms bu lt on the d^9s ion characterized by doublet and quartet terms The deepest term of this system is a metastable D term which is inverted and very low The separation of this deep lying D (d^9s) term can be found approximately by the relativistic doublet formula and by a knowledge of the D (d^9s) difference of the next higher ion As both these sources of nformation were available att mpts were made to ident fy this inverted D term Further in Cu I Zn II Au I etc The metastable D term s found to combine strongly with the regular P term (d p) and with the quartet terms a ising from the d^9sp configuration The recent analysis of the second spark spect um of Thallium by the author has shown that these terms are found in the spectrum of Tl III[17] After the publication of the above mentioned report by the writer Smith published a preliminary report of a similar inv stigation where he suggests an alternative classification which without adducing any reasons he mentions as more p obabl From the application of the relativistic doublet law to isoelectronic spectra (Au I Hg II Tl III and Pb IV) and from a study of the progressive variation Δ Z in the homologous spectra C IV S IV Ge IV & Sn IV it was thought from the beginning of this investigation that $(2^2P_2-2^2P_1)$ should be of the ord r of 7 000±600 With the aid of the information available to the author regarding the stages of ionisation of the spectral l nes in the visible a id quartz regions a search was made for the frequency recurrence among the Pb IV l nes and it was found that there were three alternative schemes as constituting the probable doublet systems with (2 P —2 P) = 6838 7131 8063 respectively It is the pairs of the wave-lengths with the last mentioned frequency difference that were given by Smith as the more probable. Relativity doublet sequence and progression of $\frac{\Delta}{Z}$ for the doublet separations are given in Tables XXI and XX The doublet systems classified by the write are given in Table XXI

TABLE XVIII —PAIRS WITH FREQUENCY DIFFERENCES

6838	7131	8063
24139	23903	240 8
30979	31037	32749
26730	25573	25229
33567	32704	33294
32362	34032	31780
39200	41162	39847
33007	36325	32548
39847	43458	40613

TABLE XIX —REGULAR DOUBLET SEQUENCE

	1 P_{12}	$\sqrt[4]{\Delta}$	2 $P_{12}\Delta$	$\sqrt[4]{\Delta}$
Au I	3815	7 859		
Hg II	91227	9 773	3672	7 76
Tl III	14811	11 031	5682	8 60
Pb IV	21060	12 047	7130	9 17

TABLE XX —VARIATION OF DOUBLET SEPARATION WITH Z

At. N Z	Element	2P —2P	Δ /Z^2	1P —1P	Δ /Z
6	C IV			107 4	2 983
14	Si IV	162	826	460 0	2 347
32	Ge IV	942	92	2790	2 726
50	Sn IV	2177 4	871	6507	2 602
82	Pb IV	7130	1 0	21060	3 130

TABLE XXI.—DOUBLET SYSTEMS OF Pb. IV.

	λ		ν	
$1^2S_1—1^2P_1$	1313·2	(9)	76150	21060
$—1^2P_2$	1028·7	(10)	97210	
$1^2P_2—1^2D_2$	1145·0	(3)	87336	
$—1^2D_3$	1116·2	(4)	89590	21065 2254
$1^2P_1—1^2D_2$	922·5	(4)	108401	
$1P—2^2S$	1123·45	(3)	89012	21055
$1^2P_1—2^2S_1$	908·54	(5)	110067	
$2^2S_1—2^2P_1$	4182·40	(8s)	23903	71 33
$—2^2P_2$	3221·00	(10)	31037	
$1^2D_2—2^2P_1$	3909·29	(5d)	25573	
$^2D_3—\ P_2$	3280·09	(9)	30478	7131 2226
$^2D_2—\ P_2$	3056·84	(4)	32704	
$2^2P—2^2D_3$	2937·55	(4)	34032	
$—\ D_3$	2864·45	(10)	34900	868 7130
$2^2P_1—\ D_2$	2428·70	(8bd)	41162	
$2^2P_2—3^2S_1$	2752·15	(1)	36325	7133
$P_1—3^2S_1$	2300·35	(4s)	43458	
$2^2D_2—2^2F_3$	3483·46	(9)	28699	875
$D_3—\ F_3$	3592·95	(6s)	27824	

In the first place it should be mentioned that 8,063 given by Smith as 2 $^2P_{12}$ is found to be abnormally high from the relativistic doublet sequence and from the progressive variation of $\Delta\nu/Z^2$ in the homolagous spectra, as shown in the preceding tables. Further, justification for the difference 7130, reported by the author is afforded by the location and identification of the following triplet as 6s[1] ^{2}D-7p ^{2}P.

TABLE XXII.

$d^{10}p/d^9s^2$	$^2D_3$	21019	$^2D_2$.
$^2P_1$	...		804·55 (1)
(7130)	...		124293
$^2P_2$	655·82 (3)		760·90 (0)
	152439		131420

There is no evidence of a similar combination with either of the remaining two separations. That the difference 21019 cm^{-1} represents the difference $^2D_3—\,^2D_2$ (d^9s^2) of Pb. IV seems to be confirmed by the following comparison with $^3D_{13}$ (d^9s) of the next higher ion.

TABLE XXIII.

Cu.	Ag.	Zn.	Cd.	Tl.	Pb.	
2070	4574	2754	5764	18865	21300(?)	d^9s
2043	4472	2719	5635	18618	21019	d^9s^2

The combinations of this deep lying inverted D term with the quartet terms of the group (d^9sp) are given in the following table —

TABLE XXIV

6p /6	D	D
^4F		1407 8 (1)
		71033
F	1749 9 (1)	1279 5 (3)
	57146	78167
F	1439 2 (2)	1104 8 (od)
	69478	90510
D		1308 2 (2)
		76441
D	1437 1 (1d)	1103 6 (od)
	69585	90613
D	1233 6 (3)	979 47 (2)
	81068	102096
D	1096 5 (1d)	
	91189	
^4P	1362 60 (0)	1059 3 (1)
	73381	94400
P	1087 34 (2)	884 98 (6)
	91968	112997
P		

Summary and conclusions :

The spark spectrum of Lead has been photographed from λ7000 to λ2000 by using powerful excitation, with a quartz spectrograph and a 10 feet concave grating using iron arc as the standard Many new lines have been measured mostly produced by the higher stages of ionisation The wave numbers wavelengths intensities together with the stages of ionisation of the prominent ones have been tabulated

A critical differentiation of the lines belonging respectively to Pb I Pb II Pb III Pb IV resulted from a careful scrutiny of the spectra obtained under varying degrees of excitation

The analysis of the second and third spark spectra of the element has been discussed in relation to the theoretical expectations and with the accurate and extensive data at hand it has been shown that the spectral structures of Pb III and Pb IV are in all details in complete agreement with Hund s correlation of spectral terms with electron onfigurations

The present analysis illustrates in a very convincing manner the utility of the study of the spectra of an element under varying degrees of discharge

In conclusion I wish to express my gratitude to Dr T Royds the Director of the Kodaikanal Observatory and to Dr A. L Narayan the Assistant Director for their active interest and much helpful criticism throughout the progress of the work My thanks are also due to the Syndicate of the Madras University for the award of a studentship which has made this work possible

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Explanation of plates.

I and II Spark Spectra of Lead, Concave Grating Spectrograph.

III and IV Spark Spectra of Lead, Quartz Spectrograph, with increasing inductance a, b, c, d.

KODAIKANAL,
22nd December 1930.

A. S. RAO,
Research Scholar.

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Plate I.
Pb (conc. grating.)

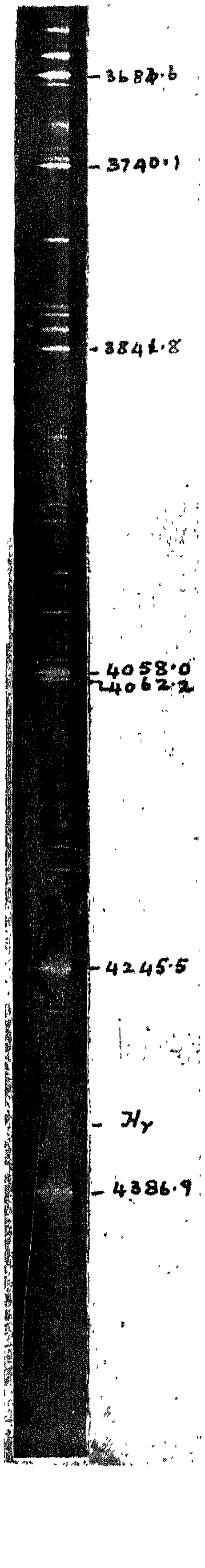

Plate II.
(Pb. conc. grating.)

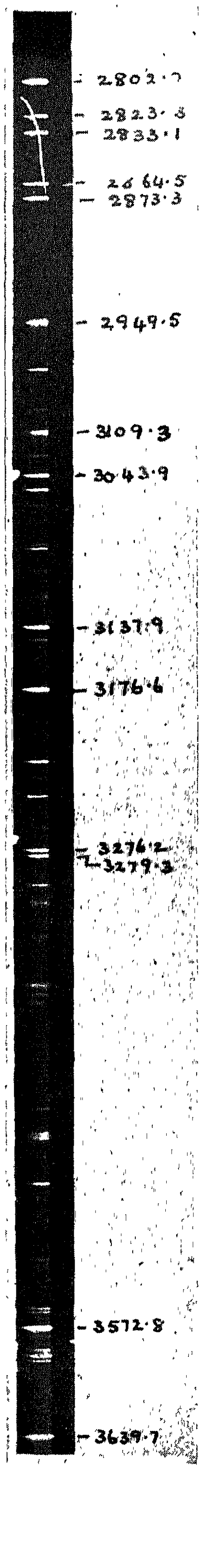

Plate III.
(Pb. quartz.)

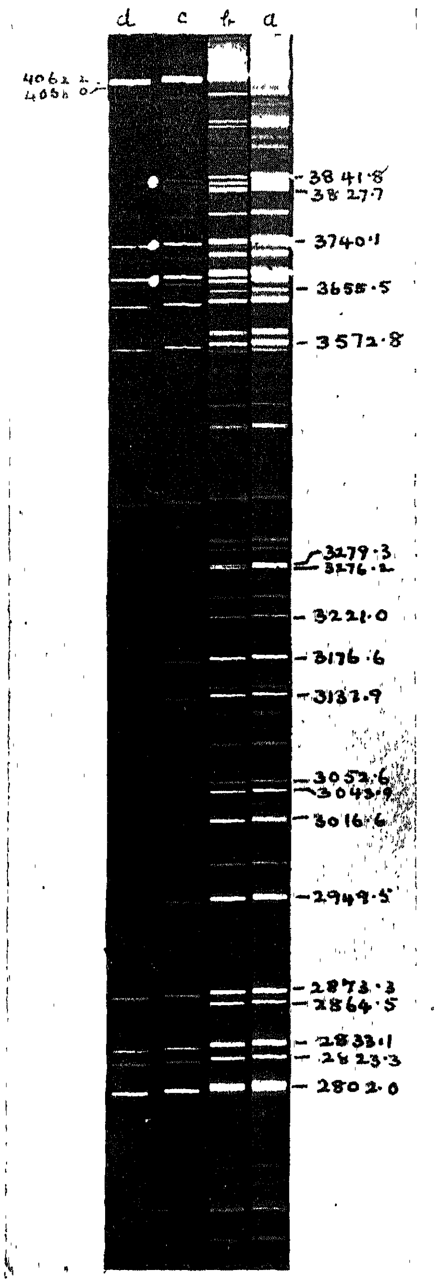

Plate IV.
(Pb. quartz—*cont.*)