SEPTEMBER 1, 1932 PHYSICAL REVIEW VOLUME 41

Survey of the K-Satellites

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(Received June 4, 1932)

A survey of the α-satellites from Ge (32) to Mg (12) reveals new lines in the $K\alpha'$ series, from the element Ca (20) to Va (23). The $K\alpha_{3,4}$ doublet is resolved over five additional elements, from Ca (20) to Mn (25). The $K\alpha_3$ line is shown to have two components, $K\alpha_3$ and $K\alpha_3'$, over the range of elements Al (13) to Cl (17). Microphotometer records, tracings of which are shown, reveal a significant reversal in the relative intensity of $K\alpha_3$ and $K\alpha_4$. This reversal is an atomic phenomenon and is not dependent upon chemical combination.

The survey of the β-satellites from Cu (29) to Cl (17) adds two new lines of the $K\beta''$ series in the elements Cr (24) and Cl (17), four new lines in the $K\beta\eta$ series from Va (23) to K (19), and reveals two new series, named $K\beta^{\text{IV}}$ and $K\beta^{\text{V}}$. The $K\beta^{\text{IV}}$ series was found in three elements; *viz.*, Sc (21), Ca (20) and K (19) while the $K\beta^{\text{V}}$ series, which starts at the element (20), extends downward to Cl (17) and probably farther. While none of the points in the new series was obtained from the free elements, the behavior of their semi-Moseley diagrams resembles those of the other β-satellites. To relate all the β-satellites to $K\alpha_2$ rather than $K\beta_1$, as has been customary, is shown to be of great convenience in the experimental study and classification of the β-satellites; the physical significance of this mode of representation, however, is problematic.

Introduction

As a result of some measurements on the satellites of the diagram lines $L\alpha_1$ and $L\beta_2$ over the range of elements R(37) to Sn(50), Richtmyer and Richtmyer[1] were able to show that the satellite lines were more numerous than had previously been reported and that carefully timed exposures were necessary to bring out the satellite lines. This fact alone would warrant a survey of the K-satellites. By making the dispersion as great as possible both by the selection of crystals, which would give large Bragg angles, and by trying exposures in high orders, it was hoped so to separate the satellites from the diagram lines as to reduce the error in the wave-length determinations. However, after several unsuccessful attempts in higher orders the survey was limited to first order spectrograms.

Microphotometer records of all spectrograms gave some notion of the relative intensities of the satellites among themselves, but, due to the very great over-exposure of the diagram lines, no idea of the intensity of the satellites in comparison with the diagram lines.

Apparatus and Procedure

All spectrograms were taken on a Siegbahn vacuum spectrograph of the relative wave-length type. The slit width, in nearly all exposures, was 0.08 cm and the distance from the slit to the photographic plate was 36.728 cm. The source of electrons was a heated tungsten spiral. The high potential across the x-ray tube was obtained from full wave rectification of the second-

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[1] Richtmyer and Richtmyer, Phys. Rev. **34**, 574 (1929).

ary voltage of a transformer, with suitable condensers to reduce the voltage fluctuations to a ripple of about 5 percent. To prevent the visible light from reaching the photographic plate, the slit was covered with carbon paper, which works very satisfactorily down to and including Mg (12).

A calcite crystal was used for all spectrograms in the range of elements from Ge (32) to S (16); a quartz crystal on the elements P (15), Si (14) and Al (13); a gypsum crystal on the elements Al (13) and Mg (12). Pure elements were employed for target materials, whenever possible, to avoid the effect of chemical combination. Materials, other than pure elements, are listed in Table I.

TABLE I. *Spectrograms of elements in chemical combination.*

Element	Material used for spectrogram
Va 23	$H_4V_2O_7$ on copper target
Sc 21	Sc_2O_3 on copper target
Ca 20	CaO on copper target
K 19	K_2SO_4 on copper target
Cl 17	NaCl on aluminum target
S 16	Al_2S_3 on aluminum target
P 15	(Fe-Phos.) alloy on copper target

The procedure followed in taking each spectrogram consisted in making enough preliminary runs to find a method by which the material could be kept upon the focal spot and to obtain the exposure necessary to bring out all the known satellites. A second spectrogram was then taken, with conditions constant, using double the above exposure.

MEASUREMENT OF THE SPECTROGRAMS

All spectrograms were measured in two different ways: (1) by means of a comparator with low magnification, approximately five; (2) from microphotometer records with a magnification of ten. All values reported in the tables represent a weighted mean of the two methods. Measurements were made to the center of the lines. Since the error of superposition[1] can be estimated on the microphotometer records, it is possible to give some weight to the psychological error of contrast, inherent in the comparator readings, by comparing the separation of two lines measured by both methods. Comparison showed that the average separation of two lines, obtained from comparator readings, differed from the separation of the same two lines, determined from microphotometer records, by a value which was less than the probable error in a series of comparator readings. Hence, the probable error, in a set of comparator readings, seems to be a fair criterion of the experimental error. The probable error will vary from 0.25 percent, for a satellite well separated from the reference line, to 2.00 percent for diffuse satellites close the reference line.

Since values of $(\Delta\nu/R)^{1/2}$ are more significant in the theory of the satellites than wave-length values, it is desirable to record values of $(\Delta\nu/R)^{1/2}$ which are determined directly from the *measured* separation of the lines by the formula,

$$(\Delta\nu/R)^{1/2} = (\Delta\lambda/\lambda^2 R)^{1/2}. \qquad (1)$$

Tables and Results

Tables II to VII give the results on the β-satellites, studied over the range of elements Cu (29) to Cl (17). The results on the α-satellites, surveyed from Ge (32) to Mg (12), are recorded in Tables VIII to XIII.

Column one gives the elements in which the satellite was measured, column two the wave-length values of the reference line taken from the tables in Vol. XXIV of the Handbuch der Experimentalphysik. The separation of the satellite from the reference line, measured on the photographic plate, is recorded in column three. Column four contains the calculated wave-length values of the satellite, while columns five and six give the values of $\Delta\nu/R$ and $(\Delta\nu/R)^{1/2}$, calculated by formula (1).

β-Satellites Referred to $K\beta$

Table II.

Elem.	β_1	cm $\Delta(\beta_1-\beta_\eta)$	β_η	$\Delta\nu/R$	$(\Delta\nu/R)^{1/2}$
19	3446.80	0.264	3488.67*	3.17	1.78
20	3083.43	0.301	3126.06*	4.08	2.02
21	2773.94	0.268	2813.16*	4.58	2.14
22	2508.98	0.240	2545.86*	5.34	2.31
23	2279.72	0.237	2315.25	6.25	2.50
24	2080.59	0.213	2113.54	6.98	2.64

Table III.

Elem.	β_1	cm $\Delta(\beta_1-\beta')$	β'	$\Delta\nu/R$	$(\Delta\nu/R)^{1/2}$
20	3083.43	0.0810	3094.92	1.102	1.050
21	2773.94	0.0632	2783.20	1.096	1.047
22	2508.98	0.0555	2517.31	1.208	1.099
23	2279.72	0.0399	2285.85	1.105	1.051
24	2080.59	0.0331	2085.78	1.092	1.045
25	1906.19	0.0286	1910.68	1.132	1.064
26	1753.01	0.0216	1756.48	1.020	1.010
27	1617.44	0.0190	1620.46	1.051	1.025
28	1497.05	0.0152	1499.48	0.988	0.994

Table IV.

Elem.	β_1	cm $\Delta(\beta_1-\beta'')$	β''	$\Delta\nu/R$	$(\Delta\nu/R)^{1/2}$
17	4394.60	0.0546	4385.49*	0.52	0.72
19	3446.80	0.0635	3434.15	0.98	0.99
20	3083.43	0.0610	3075.84	0.824	0.908
21	2773.94	0.0482	2765.88	0.835	0.914
22	2508.98	0.0511	2501.32	1.109	1.053
23	2279.72	0.0484	2272.28	1.272	1.179
24	2080.59	0.0460	2073.46*	1.441	1.225

Table V.

Elem.	β_1	cm $\Delta(\beta_1-\beta^{IV})$	β^{IV}	$\Delta\nu/R$	$(\Delta\nu/R)^{1/2}$
19	3446.80	0.249	3397.07*	3.870	1.967
20	3083.43	0.295	3041.45*	4.012	2.006
21	2773.94	0.244	2738.10*	4.264	2.065

* Indicates new lines discovered in this research.

Table VI.

Elem.	β_1	cm $\Delta(\beta_1-\beta''')$	β'''	$\Delta\nu/R$	$(\Delta\nu/R)^{1/2}$
19	3446.80	0.211	3404.69	3.27	1.80
20	3083.43	0.2520	3047.58	3.445	1.854
21	2773.94	0.2077	2743.44	3.617	1.901
22	2508.98	0.1692	2483.55	3.688	1.920
23	2279.72	0.1433	2257.69	4.120	2.029
24	2080.59	0.1239	2061.38	4.032	2.008
25	1906.19	0.1040	1889.90	4.088	2.022
26	1753.01	0.0990	1737.39	4.630	2.152
27	1617.44	0.0920	1602.97	5.012	2.245

Table VII.

Elem.	β_1	cm $\Delta(\beta_1-\beta^{V})$	β^{V}	$\Delta\nu/R$	$(\Delta\nu/R)^{1/2}$
17	4394.60	0.0228	4390.8*	0.18	0.42
19	3446.80	0.0230	3442.2*	0.36	0.60
20	3083.43	0.0227	3080.20*	0.34	0.58

α-Satellites referred to $K\alpha_2$

Table VIII.

Elem.	α_2	cm $\Delta(\alpha_2-\alpha')$	α'	$\Delta\nu/R$	$(\Delta\nu/R)^{1/2}$
12	9867.75	0.1194	9830.31	0.3503	0.5919
13	8319.40	0.0917	8287.75	0.4168	0.6456
14	7109.17	0.2295	7079.99	0.5261	0.7253
15	6141.71	0.1593	6116.21	0.6161	0.7849
16	5363.75	0.2856	5341.69	0.6988	0.8359
17	4721.36	0.1853	4702.15	0.7853	0.8862
19	3737.06	0.1242	3710.89	1.054	1.026
20	3354.95	0.1085	3340.04*	1.208	1.099
21	3028.40	0.0945	3004.89*	1.342	1.159
22	2746.81	0.0805	2724.97*	1.430	1.196
23	2502.13	0.0731	2491.88*	1.590	1.265

Table IX.

Elem.	α_2	cm $\Delta(\alpha_2-\alpha_3)$	α_3	$\Delta\nu/R$	$(\Delta\nu/R)^{1/2}$
12	9867.75	0.208	9802.46	0.611	0.782
13	8319.40	0.1561	8265.48	0.743	0.862
14	7109.17	0.366	7062.51	0.841	0.917
15	6141.71	0.240	6103.25	0.931	0.965
16	5363.75	0.433	5330.18	1.063	1.031
17	4721.36	0.279	4692.39	1.184	1.088
19	3737.06	0.1816	3713.43	1.542	1.241
20	3354.95	0.1581	3333.21	1.760	1.327
21	3028.40	0.1362	3008.92	1.935	1.391
22	2746.81	0.1196	2729.21	2.125	1.458
23	2502.13	0.1059	2486.21	2.317	1.522
24	2288.91	0.0952	2274.36	2.530	1.591
25	2101.49	0.0861	2088.16	2.750	1.658
26	1936.01	0.0841	1922.86	3.197	1.788
27	1789.19	0.0764	1777.15	3.428	1.852
28	1658.35	0.0688	1647.43	3.618	1.902
29	1541.16	0.0667	1530.52	4.083	2.021
30	1435.87	0.0615	1426.01	4.357	2.087
31	1340.87	0.0560	1331.86	4.565	2.137
32	1255.21	0.0530	1246.66	4.947	2.224

TABLE X.

Elem.	α_2	cm $\Delta(\alpha_2-\alpha_4)$	α_4	$\Delta\nu/R$	$(\Delta\nu/R)^{1/2}$
12	9867.75	0.253	9788.30	0.743	0.862
13	8319.40	0.190	8253.75	0.859	0.951
14	7109.17	0.445	7052.34	1.023	1.012
15	6141.71	0.296	6094.23	1.149	1.071
16	5363.75	0.521	5323.26	1.283	1.132
17	4721.36	0.336	4686.23	1.428	1.198
19	3737.06	0.214	3709.22	1.824	1.350
20	3354.95	0.185	3329.50	2.061	1.436
21	3028.40	0.159	3005.66	2.260	1.503
22	2746.81	0.138	2726.46	2.458	1.568
23	2502.13	0.1219	2483.80	2.667	1.633
24	2288.91	0.1084	2272.35	2.881	1.697
25	2101.49	0.0978	2086.35	3.123	1.767

TABLE XI.

Elem.	α_2	cm $\Delta(\alpha_2-\alpha_5)$	α_5	$\Delta\nu/R$	$(\Delta\nu/R)^{1/2}$
12	9867.75	0.426	9742.65	1.255	1.120
13	8319.40	0.314	8210.80	1.429	1.195
14	7109.17	0.730	7015.40	1.690	1.300

TABLE XII.

Elem.	α_2	cm $(\alpha_2-\alpha_6)$	α_6	$\Delta\nu/R$	$(\Delta\nu/R)^{1/2}$
12	9867.75	0.503	9718.35	1.483	1.218
13	8319.40	0.377	8189.90	1.717	1.310
14	7109.17	0.804	7005.77	1.822	1.366

TABLE XIII.

Elem.	α_2	cm $\Delta(\alpha_2-\alpha_3')$	α_3'	$\Delta\nu/R$	$(\Delta\nu/R)^{1/2}$
14	7109.17	0.388	7058.77	0.892	0.945
15	6141.71	0.257	6100.51*	0.995	0.997
16	5363.75	0.462	5327.90	1.135	1.066
17	4721.36	0.300	4690.20*	1.274	1.129

THE $K\alpha'$-SATELLITE

Four new lines were found in the $K\alpha'$ series, extending the series from K (19) to Va (23). However, there is a possibility of finding this satellite in a few more elements above V a(23) with very long exposures, since this line presents the behavior of gradually fading out in the elements of higher atomic number. Deodhar[2] reports, for Si (14), two components of $K\alpha'$. However, the doublet character of $K\alpha'$ is very problematic since this structure was noted in only one element and since Deodhar's careful reexamination of Bäcklin's[3]

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[2] Deodhar, Proc. Roy. Soc. **A131**, 633 (1931).

[3] Bäcklin, Zeits. f. Physik **33**, 547 (1925).

original plate on silicon failed to show any trace of structure in the $K\alpha'$ line. Moreover, no trace of the doublet nature of $K\alpha'$ was found on any spectrogram of this survey although the dispersion of the author's spectrograph was greater than Deodhar's. Since quartz crystals were used in both spectrographs, the dispersion ratio of the two spectrographs is the ratio of the distances from slit to photographic plate, namely, 36.728/27.596. Intensity considerations can scarcely be urged for the failure of other observers to find the structure of $K\alpha'$ since silicon is one of the very convenient elements to handle on the focal spot.

THE $K\alpha_{3,4}$ DOUBLET

The $K\alpha_{3,4}$ doublet was measured over the range of elements from Mg(12) to Ge(32). The extension of this doublet from Zn(30) to Ge(32) confirms the findings of Richtmyer and Ramburg[4] who first detected and measured the line in any element above Zn(30).

Resolution of $K\alpha_{3,4}$ has been reported in the literature from Na(11) to Ca(20). However, the plates obtained on this spectrograph, with the rather large dispersion noted above, show distinctly the components of the doublet from Ca(20) to Mn(25). Resolution of $K\alpha_{3,4}$ above the element Mn (25) was attempted with second order exposures, but a 22 hour exposure on Co(27) with 15 k.v. and 20 m.a. did not yield the resolution expected. The two values of $K\alpha_3$ and $K\alpha_4$ for Cu(29), Fig. 2, were taken from data obtained by Richtmyer and Taylor[5] on a double crystal x-ray spectrometer. It is seen that the two points thus determined fit the semi-Moseley diagrams plotted from the data of this survey.

That the $K\alpha_3$ line consists of two components was first observed by Bäcklin[3] in the case of Si(14). Deodhar[2] confirms the doublet nature of $K\alpha_3$ for Si (16). However, the doublet structure of $K\alpha_3$ extends over more elements than reported by Bäcklin and Deodhar. During this work, the complete resolution of $K\alpha_3$ into its components has been observed in five elements, from Al(13) to Cl(17). To show the components of $K\alpha_3$ for Al(13) it was necessary to take a spectrogram with a quartz crystal, for which the Bragg angle was $78^{\circ-22'}$. Although the value of $K\alpha_3$, reported in Table IX, was obtained from a spectrogram of Al, with a gypsum crystal, on which $K\alpha_3$ was not resolved into its components, the two points on the semi-Moseley diagram, Fig. 2, were calculated from the separation of $K\alpha_3$ and $K\alpha_3'$ on the Al-quartz plate. The components of $K\alpha_3$ for the elements Si(14), *P*(15) and S(16), are shown on the tracings of the microphotometer records of these plates, Fig. 1.

Contrary to the observation of Deodhar,[2] on the $K\alpha_4$ line of Si(14), no indication of structure in this line was found on any spectrogram. Surely the aluminum spectrogram, with the quartz crystal, on which the $K\alpha'$, $K\alpha_3'$ $K\alpha_3$ and $K\alpha_4$ lines were widely separated, should have put in evidence the components of $K\alpha_4$ if they could be resolved. However, no trace of structure was noted.

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[4] Richtmyer and Ramburg, Phys. Rev. **35**, 661 (1930).

[5] Richtmyer and Taylor, Phys. Rev. **36**, 1044 (1930).

Microphotometer records, tracings of which are shown in Fig. 1, show a reversal in the relative intensities of $K\alpha_3$ and $K\alpha_4$ between the elements P(15) and S(16). For the elements Mg(12), Al(13), Si(4)1 and P(15) $K\alpha_3$ is definitely more intense than $K\alpha_4$, although the difference decreases as the atomic number of the element increases. From S(16) to Mn(25), the range of elements for which $K\alpha_3$ and $K\alpha_4$ are resolved, $K\alpha_4$ is the more intense line. While it is known that chemical combination can produce changes in the relative intensity[6] of some lines, the reversal in the relative intensity of $K\alpha_3$ and $K\alpha_4$ is an atomic phenomenon; the reversal still exists if the spectrograms of elements, to be had only in the form of chemical compounds, are disregarded. While the spectrograms of P(15) and S(16) were obtained from compounds of the elements, an examination of the calcium spectrogram, the next element after Si(14) to be had in the pure state, shows the greater intensity of the $K\alpha_4$ line.

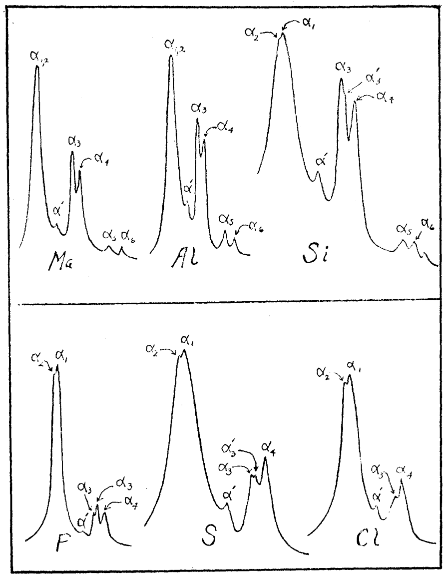

Fig. 1. Tracings of microphotometer records.

The reversal in the relative intensity of the components of the $K\alpha_{3,4}$ doublet is all the more significant when compared to the behavior of the components of the diagram doublet $K\alpha_{1,2}$ in which the intensity ratio of the $K\alpha_1$ line to the $K\alpha_2$ line is 2:1 for the whole range of elements over which measurements have been made.

THE $K\alpha_5$ AND $K\alpha_6$ SATELLITES

The $K\alpha_5$ and $K\alpha_6$ satellites were detected and measured for only three elements Mg(12), Al(13) and Si(14). Hjalmar[7] reports a measurement on

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[6] Handbuch der Experimental Physik, p. 45.

[7] Hjalmar, Zeits. f. Physik, **1–2,** 439 (1920).

$K\alpha_5$ for S(16) and, recently Deodhar[2] reports measurements on $K\alpha_5$ and $K\alpha_6$ for P(15), S(16) and Cl(17).

THE $K\beta_\eta$ SATELLITE

The β_η satellite, a very faint diffuse line, probably complex in structure, at least in the lower elements for which it can be found, was detected and measured in six elements, K(19) to Cr(24). This satellite is situated upon the long wave-length side of $K\beta_1$ and, because of its faint diffuse character measurements are difficult. The accuracy with which its wave-length can be determined compares unfavorably with that of the other lines, probably reaching an error of three percent of the measured wave-length difference between $K\beta_1$ and $K\beta_\eta$. Beuthe[8] has measured this line from Va(23) to Ge(32). The combined results of the two experiments give this satellite a range from K(19) to Ge(32).

THE $K\beta'$ SATELLITE

The β'-satellite, upon the long wave-length side and close to $K\beta_1$ was detected and measured over the range of elements from Ca(20) to Ni(28). The present work adds no element to this series, values of which are reported for the elements as low as Si (14), although no difficulty was experienced in verifying it. Dolejsek and Felcakova[9] present data to show that the $K\beta'$ line is a complex line. For elements below Mn (25) these authors claim to have found that $K\beta'$ consists of two unresolved doublets which in the case of the higher elements are superimposed. The appearance of the $K\beta'$ line on the spectrograms obtained in the course of this work does not warrant agreement with this conclusion. However, densitometer records show that the intensity ratio $K\beta_1:K\beta'$ becomes greater for oxides than for free elements; hence, as oxides were used in the spectrograms of the elements Ca (20) and Se (21) and Ti (22), where the dispersion was greatest, it may be that the $K\beta'$ lines were not heavy enough to bring out the structure.

THE β''-SATELLITE

The β''-satellite between $K\beta_1$ and $K\beta_2$ was measured from Cl (17) to Cr (24). These data add two more elements to the series as found by Druyvesteyn,[10] *viz.*, the elements Cr(24) and Cl(17). Kawata,[11] however, obtained this satellite on spectrograms from Fe(26) to Zn(30). Hjalmar[12] reports a wave-length value of 4390.8 (x.u.) for the $K\beta''$ line of Cl(17), while the chlorine spectrogram obtained during this work showed two lines of wave-length values 4390.8 and 4385.5 (x.u.). When the $(\Delta\nu/R)^{1/2}$ values corresponding to these wave-lengths are added to the semi-Moseley diagrams it is the 4385.5 value which falls on the graph of the $K\beta''$ series. The 4390.8 line belongs to a

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[8] Beuthe, Zeits. f. Physik, **60**, 603 (1929).

[9] Dolejsek and Felcakova, Nature **123**, 412 (1929).

[10] Druyvesteyn, Zeits. f. Physik **43**, 707 (1927).

[11] Kawata, Mem. Kyoto Imp. Univ. **A13**, No. 6, 1930.

[12] Hjalmar, Zeits. f. Physik **7**, 341 (1921).

series, here called $K\beta^{V}$, which apparently starts at Ca(20) and extends downward. The combined results of all measurements on the $K\beta''$ lines give it a range from Cl(17) to Zn(30), with the exception of Mn(25).

THE β'''-SATELLITE

The β'''-satellite upon the short wave-length side and close to $K\beta_1$ was measured over the elements Cl(17) to Co(27). Kawata[11] measured this line for the element Ni(28). Beuthe[9] measured a line which he called $K\beta_y$ for several of the elements from Va(23) to Y(39). The values which he reports for $K\beta_y$ from Va(23) to Ni(28) coincide with other reported values of $K\beta'''$ so it has been assumed that $K\beta'''$ extends to Y(39). However, the points above Cu(29) may constituted a new series since the line in this range of elements appears on the long wave-length side of $K\beta_2$. Moreover, the semi-Moseley diagram of the points above Cu(29) has a different slope from the semi-Moseley graph of the points below Cu(29).

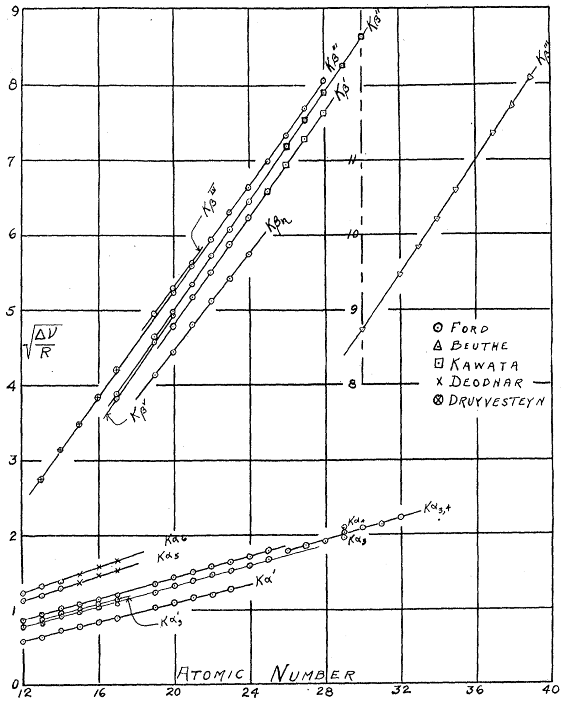

Fig. 2. The semi-Moseley diagrams of all the K-satellites referred to $K\alpha_2$.

THE β^{IV}-SATELLITE

This new line was found on the spectrograms of Ca(20), Sc(21) and K(19), all of which were run with compounds of the elements on the focal spot. Although chemical combination throws some doubt upon the validity of this series it presents the same behavior as all the β-satellites. See Fig. 2.

THE β^{V}-SATELLITE

While this satellite has been measured on only three spectrograms, its semi-Moseley diagram gives it the behavior of the other β-satellites. Again, the factor of chemical combination may be argued against its validity, but a recent spectrogram of pure Si(14), not included in the present work, shows both $K\beta''$ and $K\beta^{V}$. The fact that $K\beta^{V}$, when it first appears in calcium, is more intense than $K\beta''$ is against the view that it should be regarded as a component of $K\beta''$.

DISCUSSION OF RESULTS

In an experimental survey, it would take us too far afield to analyze the various theories which have been proposed for the origin of the satellite lines. However, the following references[13] to some of the principal papers will furnish a guide to the literature. The relation which, perhaps, correlates more experimental data than any other is that of the linearality[13] of the semi-Moseley diagrams. All the α-satellites, at least qualitatively, obey this law if $K\alpha_1$ or $K\alpha_2$ is taken to be the parent line. It makes little difference whether $K\alpha_1$ or

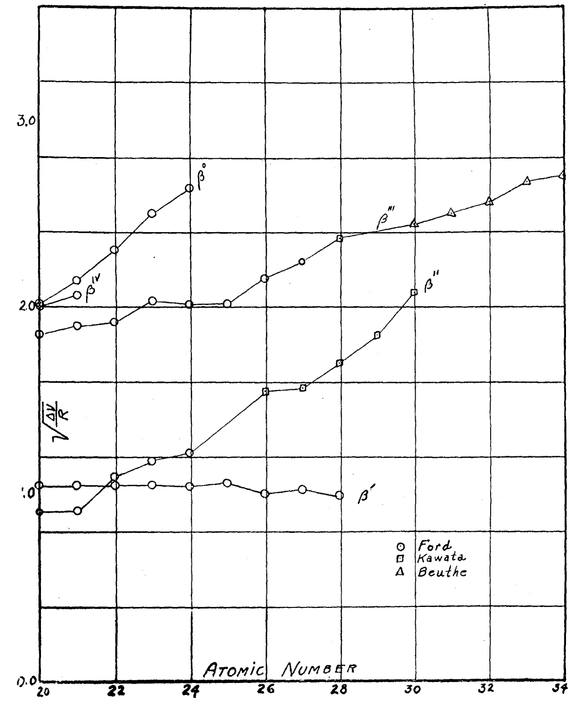

Fig. 3. The semi-Moseley diagrams of the β-satellites referred to $K\beta_1$.

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[13] Wentzel, Ann d. Physik **66,** 437 (1921); Coster, Phil. Mag. **43,** 1088 (1922); Coster, Phil. Mag. **43,** 1105 (1922); Coster and Druyvesteyn, Zeits. f. Physik **40,** 765 (1927); Druyvesteyn, Zeits. f. Physik **43,** 707 (1927); Druyvesteyn, Dissertation, Groningen; Richtmyer, J. F. Inst., **208,** 325 (1929); Beuthe, Zeits. f. Physik **60,** 603 (1930); Deodhar, Proc. Roy. Soc. **A131,** 476 (1931).

$K\alpha_2$ is chosen for the reference line; from the experimental standpoint, the probable error in the comparator reading between the satellites and $K\alpha_2$ seem a little less than the p.e. when $K\alpha_1$ is made the reference line. On the other hand the β-satellites, when referred to $K\beta_1$, about which they cluster, present poor agreement with the linear relation. Fig. 3 shows the appearance of the semi-Moseley diagrams of the β-satellites when referred to $K\beta_1$.

Deodhar,[13] seeking for a reference line which would give a better linear relation, found the desired improvement in the semi-Moseley diagrams of the $K\beta'''$, $K\beta_3$ and $K\beta_\eta$ lines by referring them to the $K\beta_1$ line. A theoretical basis for thls mode of representation can be found in an extension of the double electron transition hypothesis, which, as first proposed by Richtmyer,[13] was limited to the simultaneous transitions of two electrons, one between inner levels, and the other between peripheral levels, to include the possibility of both transitions among the inner levels. Beuthe's[13] suggestion, which is qualitatively correct, that the frequency of $K\beta'''$ derives from the addition of the frequencies of $K\alpha_1$ and $L\alpha_1$, is a specific statement of this extension.

The fact that $K\alpha_2$ serves for a reference line for the β-satellites, as well if not better than $K\alpha_1$, throws doubt upon the physical significance of this mode of representation. A recent paper by Hirsh[14] shows that the improved linearality in the semi-Moseley diagrams of $K\beta'''$, $K\beta_3$ and $K\beta_\eta$ may result from the fact that the $(\Delta\nu/R)^{1/2}$, with $K\alpha_1$ as the reference line, are larger than the $(\Delta\nu/R)^{1/2}$ values with $K\beta_1$ as the parent line. However, the improvement in the semi-Moseley diagrams of the β-satellites is not limited to the lines selected by Deodhar, but extends to all the β-satellites.

Regardless of the physical significance which may be attached to the various modes of representation, the semi-Moseley diagrams referred to $K\alpha_2$ are of great value in the experimental study and classification of the satellite lines. Two points, already mentioned, serve to illustrate this advantage. (1) Since each satellite series is characterized by a definite slope, the break which occurs in the $K\beta'''$ series at the element Ni(28) is indicative of two separate series. This observation is also confirmed by the fact that $K\beta'''$, from Ni(28) to Mg(12), appears on the long wave-length side of $K\beta_2$ while the $K\beta_y$ line, measured by Beuthe[13] from Zn(30) to Y(39), appears on the short wave-length side of $K\beta_2$. The assumption that the $K\beta_y$ line of Beuthe is an extension of $K\beta'''$ into the higher elements may be wrong, and any critical examination of the origin of the $K\beta'''$ line should be limited to the points below Cu(29). (2) The two lines, 4390.8 and 4385.5 (x.u.) of Cl(17) are definitely classified by the two semi-Moseley diagrams to which they belong.

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[14] Hirsh, Phys. Rev. **40**, 151 (1932).