U. S. DEPARTMENT OF COMMERCE NATIONAL BUREAU OF STANDARDS

RESEARCH PAPER RP1008

Part of Journal of Research of the National Bureau of Standards, Volume 19, July 1937

ARC AND SPARK SPECTRA OF LUTECIUM

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ABSTRACT

A new description of conventional arc and spark spectra of lutecium (cassiopeium) in the wave-length range 2000 to 11000 A has been completed. Wave-length measurements and intensity estimates are presented for 650 lines, 25 of which represent band heads presumably due to LuO, 250 are characteristic of neutral Lu atoms (Lu I spectrum), 370 of singly ionized atoms (Lu II spectrum), and the remainder probably belong to doubly ionized atoms (Lu III spectrum). These data should aid in the spectroscopic identification and analysis of lutecium and serve as a basis for further study of spectral structures, hyperfine structures, and Zeeman effects.

CONTENTS

I. INTRODUCTION

The chemical elements with atomic numbers 58 to 71, inclusive, known as the rare-earth group, are characterized by nearly identical chemical properties which prevent their complete separation or purification by chemical means [1].[1] Slight differences in physical properties permit partial separation from each other (by fractional crystallization or by electrolysis), but it is doubtful if any rare-earth element of *spectroscopic purity* has ever been available for study. Impure rare-earth materials, or misidentification of spectra, account for the mistaken discovery of new elements, such as demonium, by Rowland; incognitium and ionium, by Crookes; celtium, by Urbain; denebium, dubhium, eurosamarium, and welsium, by Eder [2].

The atomic-emission spectra of these elements are characterized, in general, by great complexity and considerable variability depending on the type of excitation. The complexity (aside from impurities) is due in part to large families of spectral terms, usually of high multiplicity [3], and in part to relatively low ionizing potentials [4] which result in the excitation of several successive atomic spectra in addition to rather complicated molecular spectra. The most extensive published descriptions of these spectra were made more than a quarter of a century ago by Exner and Haschek [5], and a tabulation of the number of lines they observed in arc and spark spectra gives some idea of the relative complexity of the spectra of rare-earth elements. See table 1.

[1] Numbers in brackets refer to literature citations at the end of this paper.

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TABLE 1.—*Number of lines published for rare-earth spectra by Exner and Haschek* [5]

Atomic number	Chemical symbol	Number of lines	
		Arc spectrum	Spark spectrum
58	Ce	2,894	1,758
59	Pr	2,490	1,732
60	Nd	2,762	2,540
61	Il	------	------
62	Sm	1,679	1,085
63	Eu	857	1,508
64	Gd	1,687	1,401
65	Tb	2,487	1,379
66	Dy	3,312	1,464
67	Ho	1,482	1,222
68	Er	2,321	1,785
69	Tm	1,007	667
70	Yb	905	795
71	Lu	164	236

The past 15 years has been an epoch-making period for the development of the quantum theory and for the analysis of complex spectra, but the rare-earth group was the last to succumb to analysis. Taking advantage of the relative simplicity of Lu spectra, and guided by comparisons with theoretically similar spectra, the present authors succeeded in finding the first regularities [6], which were published in 1930. It was first necessary, however, to make new descriptions of the spectra since the older data were incomplete and unreliable. The purpose of the present paper is to make public, for purposes of spectroscopic identification, our complete description of the conventional arc and spark spectra of lutecium.

The first data published concerning Lu spectra consisted of 33 wave lengths (2701.8 to 3647.9 A) by Urbain [7] and 62 lines (2603.38 to 6222.6 A) by Auer von Welsbach [8], both of whom discovered the element practically simultaneously, the former naming it lutecium (Lu) and the latter cassiopeium (Cp). A little later Exner and Haschek [5] gave values for 164 arc lines (2392.26 to 6945.30 A) and 236 spark lines (2195.64 to 6463.38 A). Some information concerning lines characteristic of neutral and of ionized atoms may be gleaned from a comparison of these arc and spark tables, but the separation by means of these data is often false or ambiguous. In 1910 Eder and Valenta [9] published 48 lines (5476.94 to 7126.23) observed in the arc spectrum, and in 1911 gave reproductions of spectrograms [10], a table of 116 wave lengths for the arc spectrum (2390.84 to 7126.23 A) and 79 wave lengths for the spark spectrum (2603.38 to 6463.31 A). In 1915 Eder [11], having obtained a purer sample from Auer, published a new description of the arc spectrum listing 263 lines (2397.17 to 7237.89 A), but many of these are not now identifiable with Lu. Considering the briefness of published lists, the poor quality of early observations, the limited range of spectra, and the impure materials used, it must be admitted that the description of Lu spectra was in a very unsatisfactory state, and the necessity for making new observations before analysis of spectral structure could succeed is apparent. Our preliminary report on regularities in Lu spectra gave improved data for 100 classified lines [6]. A temperature classification of Lu spectra by King [12] lists 102 lines showing perfect agreement with our separation of lines according to excitation stages. Incidentally, it may be added that the close coincidence of a strong Lu I line with the almost omnipresent Ca II line, 3968.47 A, noted by King, was mentioned 20 years earlier by Eder and Valenta [10.]

II. EXPERIMENTS

Our first measurements of Lu spectra were made in 1929 with a sample of lutecium oxide obtained from Eder 10 years earlier. It was part of his collection of rare earths prepared by Auer. This sample contained a considerable amount of Yb and some Tm, so that it was not possible to complete the description of Lu spectra without also investigating those of Yb and Tm. The Eder collection just referred to contained a sample of ytterbium oxide but lacked any specimen of Tm salt. The Yb was found to be contaminated with both Lu and Tm, so the identification of Lu and Yb lines could be effected, but considerable uncertainty remained about the removal of all Tm impurity lines from either Lu or Yb. When this situation was explained to Professor B. S. Hopkins, he kindly presented new samples of Lu, Yb, and Tm oxides prepared at the University of Illinois. With these materials we were able to check and extend our former lists of Lu and Yb lines, and also to make greatly improved descriptions of Tm spectra. This work was facilitated by the comparative purity of the Illinois samples. Although the Lu spectrograms show many Yb and some Tm lines, and the Tm spectrograms show both Yb and Lu, the best Yb sample is practically free of both Lu and Tm.

In order to insure the correct assignment of spectral lines to their origin, both as regards chemical element and stage of ionization, two procedures were followed: (1) The spectra of Lu, Yb, and Tm (and Er) were photographed side by side so that each line could be ascribed to the proper element on the basis of intensities, and (2) arc and spark spectra of each element were photographed in juxtaposition, so that intensity comparisons would separate lines from different excitation stages. In each case the rare-earth salt was fused on pure silver or copper electrodes for the production of arc spectra, and the identical silver electrodes were used in making spark spectrograms. Each pair of spectrograms was flanked by iron spectra for wave-length measurements, and the latter by blank spectra of the silver or copper. The arcs were operated with direct current of 5 amperes and applied potential of 220 volts, while the sparks were generated by high voltage (10,000 to 40,000) discharges from mica condensers of 0.006-microfarad capacity connected parallel with the spark in the secondary circuit of the transformers.

Ultraviolet spectrograms from 2000 to 3000 A were made with a Hilger E_1 quartz spectrograph. The interval 2500 to 8500 A was photographed with concave-grating spectrographs having either 15,000 or 20,000 lines per inch, while 7500 to 11000 A was studied with a similar grating spectrograph having 7,500 lines per inch. The dispersion values for the first-order spectra of the gratings are 5.0, 3.7, and 10 A/mm, respectively. Since only a fraction of a gram of each salt was used for making all the required spectrograms, it was imperative to get the maximum efficiency out of the spectrographs.

Hilger Schumann plates were used for the shortest waves, Eastman 33 plates covered the region 2300 to 4800 A, and sensitized plates (*EK* types *F*, *N*, *Q*) recorded the longer waves [13].

III. RESULTS

All wave-length measurements were made relative to iron standards (except 2000 to 2200 A, which was measured relative to copper standards), the values being those adopted by the International Astronomical Union [14], or those published by Burns and Walters [15]. Every line listed in table 2 was observed on two or more spectrograms (except a small number with questioned intensities observed only on strongest exposures). The stronger Lu lines were measured on 5 to 10 spectrograms, and many of them were measured an equal number of times on Yb and Tm spectrograms, where they appeared as impurities. The concordance of values from different spectrograms and the coincidence of wave lengths with impurity lines indicates that the final results for most lines are correct within 0.01 A, but errors of 0.02 A or more may exist among faint lines or those showing wide hyperfine structure. In some cases, it was difficult to decide if close lines represented fine or hyperfine structure, but our intention was to give only the center of gravity of complex lines. This hyperfine structure of Lu lines, first mentioned by the authors [6], was further commented on by King [12], and then studied in some detail by Schüler and Schmidt [16], and by Gollnow [17]. A nuclear moment of 5/2 was first announced [18] for 175 Lu, but this was later [16] increased to 7/2. Gollnow [17] reported the discovery of a new Lu isotope (mass number 173 or 177) whose relative abundance is estimated at 1.5 percent, and whose spin is 7/2 or possibly 9/2. Although the hyperfine structure of Lu lines is not resolved in our spectrograms, it widens some of the line images to 1 A or more, and may thus result in some uncertainty as to the centers of gravity and perhaps leads to overestimated intensities of wide lines. Some notes about *hfs* are given at the end of table 2.

Wave-length measurements and estimated relative intensities for 650 lines characteristic of Lu atoms are presented in table 2. About 250 of these lines belong to neutral atoms, 370 to singly ionized atoms, and 5 or 6 to doubly ionized atoms. In addition, some 25 band heads presumably due to LuO are given. Since spark spectra were not observed above 6800 A, the assignment of longer waves to I and II spectra is based principally on the term analysis of these spectra, and may possibly require some slight corrections when these analyses are completed. It is not unlikely that a few real Lu lines may have been discarded on account of coincidence with impurity lines, but the greatest deficiency in this description is probably in Lu spark lines masked by silver lines, or by air lines, and unobserved above 6800 A, unless they appear in the arc spectrum. The number of classified lines in Lu I and Lu II spectra has been increased to 200, but details of these analyses will be postponed until more complete and until Zeeman effects required for the interpretation of the spectral terms have been observed.

The strongest line characteristic of neutral Lu atoms is 6004.52 A, or possibly 4518.57 A, while the strongest line characteristic of singly ionized atoms is 5476.69 A with 6221.87 A and 6463.12 A next. It may be expected that the most intense lines will also be the most persistent or sensitive for detecting minute traces of Lu, so any sources in which neutral atoms predominate (flames, low-voltage arcs) should be examined for 6004.52 A, but if ionized atoms are most abundant

5476.69 A will reveal the lowest concentration of Lu. It appears that on account of the easy ionization of Lu atoms, the strongest Lu II lines have greater intensity than any Lu I lines in the ordinary 220-volt arc with short gap, and 5476.69 and 6221.87 A may be regarded as the most persistent lines of conventional arc and spark sources.

Attention is called to the fact that 19 of the 24 lines published by Urbain [19] as characteristic of "celtium" are now identified as lutecium.

TABLE 2.—*Arc and spark spectra of lutecium* ($Z=71$)

c=Complex, hyperfine structure (*hfs*).
d=Double, may be *hfs*.
e=Enhanced at electrode.
h=Hazy.
H=Very hazy.

l=Shaded or displaced to longer waves.
B=Band head.
p=Part of band structure.
I=Spectrum of neutral atoms.

II=Spectrum of singly ionized atoms.
III=Spectrum of doubly ionized atoms.
LuO=Molecular spectrum.

λ_{air} A	Intensity and character		Spectrum	λ_{air} A	Intensity and character		Spectrum	λ_{air} A	Intensity and character		Spectrum
	Arc	Spark			Arc	Spark			Arc	Spark	
2065.42	-------	30*h*	II	2179.92	-------	1	II	2306.38	-------	1	II
2070.66	-------	3*h*	II	2180.79	-------	5	II	2307.54	-------	1	II
2071.95	-------	2 Si?	II	2182.96	-------	1	II	2310.66	-------	2*h*	II
2085.69	-------	5	II	2183.94	-------	1	II	2313.03	-------	5	II
2086.06	-------	2	II	2184.80	-------	6	II	2313.98	3	15*hl*	II
2086.45	-------	4	II	2185.42	-------	2	II	2322.61	-------	1	II
2087.50	-------	5	II	2190.14	-------	6	II	2333.04	-------	1	II
2092.14	-------	6	II	2190.77	-------	4	II	2333.41	-------	1	II
2098.94	-------	1	II	2191.37	6	60	II	2334.38	-------	2 Yb?	II
2099.54	-------	10*h*	II	2194.80	-------	7	II	2337.05	-------	3	II
2100.40	-------	2	II	2195.54	30	100	II	2338.43	-------	1	II
2101.32	-------	1	II	2196.54	-------	2	II	2341.19	-------	3	II
2104.40	-------	40	II	2196.98	-------	4	II	2343.07	2	15	II
2107.84	-------	4	II	2197.90	-------	2	II	2345.50	-------	1	II
2109.14	-------	5	II	2200.31	-------	6	II	2348.60	-------	2	II
2110.22	-------	7	II	2204.60	-------	2*h*	II	2349.14	-------	2*h*	II
2110.37	-------	4	II	2206.82	-------	5*h*	II	2350.43	-------	3	II
2117.14	-------	4	II	2207.64	-------	2*h*	II	2350.73	-------	1	II
2117.82	-------	2 Yb?	II	2216.70	-------	1	II	2351.88	-------	2*h*	II
2122.76	-------	6*h*	II	2217.32	-------	3*h*	II	2352.76	-------	1	II
2124.13	-------	3 Yb?	II	2220.96	-------	1	II	2357.28	-------	4	II
2124.64	-------	2	II	2221.74	-------	2	II	2359.38	-------	2	II
2127.43	-------	4	II	2224.02	-------	6*h*	II	2363.18	-------	1	II
2128.39	-------	5	II	2236.17	6*d e*	150*h*	III	2367.77	-------	1	II
2131.66	-------	6	II	2239.39	-------	1	II	2368.22	-------	2	II
2132.31	-------	5	II	2249.53	-------	2*h*	II	2369.08	-------	5	II
2135.18	-------	5	II	2260.40	-------	4	II	2380.57	-------	2	II
2137.72	-------	8 Yb?	II	2260.79	-------	2	II	2381.69	-------	30*h*	II, III?
2139.19	-------	6	II	2263.98	-------	3	II	2385.20	-------	1	II
2139.76	-------	1	II	2264.63	-------	2	II	2387.45	-------	1	II
2140.53	-------	2*h*	II	2269.65	-------	1	II	2388.69	-------	2	II
2143.84	-------	3	II	2269.94	-------	1	II	2390.23	-------	2	II
2146.96	-------	2*h*	II	2270.61	-------	4*h*	II	2392.19	30	100	II
2147.59	-------	2*h*	II	2270.95	-------	1	II	2394.11	-------	1	II
2150.51	-------	2	II	2271.97	-------	1	II	2394.77	-------	1	II
2151.68	-------	1	II	2276.94	8	20	II	2397.62	-------	1	II
2154.36	-------	7	II	2283.99	-------	3 Yb?	II	2398.28	-------	1	II
2155.92	-------	3	II	2291.74	-------	1	II	2399.14	10	50	II
2156.73	-------	4	II	2293.34	-------	1	II	2401.58	-------	2	II
2158.04	-------	2	II	2293.78	-------	2	II	2403.69	-------	4*h*	II
2159.91	-------	2	II	2297.41	15	100	II	2405.76	-------	1	II
2164.33	1	15	II	2298.99	-------	1	II	2406.21	-------	2	II
2173.30	-------	5 Yb?	II	2301.71	-------	1	II	2406.82	-------	2	II
2176.93	-------	4	II	2302.84	-------	1	II	2408.13	-------	1	II
2178.02	-------	8	II	2303.30	-------	2 Yb?	II	2415.92	-------	5	II

See footnotes at end of table.

TABLE 2.—*Arc and spark spectra of lutecium (Z=71)*—Continued

λ_{air} A	Intensity and character		Spectrum	λ_{air} A	Intensity and character		Spectrum	λ_{air} A	Intensity and character		Spectrum
	Arc	Spark			Arc	Spark			Arc	Spark	
2419.21	8	40	II	2555.82	------	2	II	2835.25	------	10*hd*?	II
2421.42	------	4 Yb?	II	2556.91	------	2	II	2845.13	30*h*	2	I
2421.97	------	1	II	2558.42	------	6*h*	II	2845.87	------	1*h*	II
2424.90	------	1	II	2561.80	------	6*h*	II	2847.51	40	120	II
2427.21	------	3	II	2563.52	1*e*	80*h*	III	2855.36	------	2	II
2430.26	3	15	II	2571.23	30	100	II	2860.31	------	3	II
2433.02	------	1	II	2573.55	------	2	II	2860.94	------	1	II
2434.25	------	2	II	2578.79	40	120	II	2862.74	------	1	II
2435.12	------	1 Yb?	II	2582.13	3	20	II	2863.61	------	1*h*	II
2445.83	------	1	II	2590.03	------	3	II	2876.54	------	2*h*	II
2449.75	------	2	II	2590.58	------	2	II	2879.02	------	2*h*	II
2449.96	------	2	II	2592.27	2*h*	?	I?	2885.14	40*h*	3	I
2451.60	------	1	II	2592.34	------	5*h*	II	2886.04	3	------	I
2454.87	------	2	II	2603.33 [a]	10*d, e*	300*h*	III	2894.84	60	200	II
2455.60	------	4	II	2607.32	------	4*h*	II	2900.30	50	150	II
2456.50	------	2	II	2612.86	3*h*	?	I?	2903.05	20	1	I
2457.56	------	5*h*	II	2613.40	30	100	II	2905.92	------	1	II
2459.64	3	8	II	2615.42	100	250	II	2911.39	100	300	II
2463.95	------	3	II	2619.26	30	100	II	2912.70	15*h*	------	I
2464.82	5	?	I?	2621.88	1	?	I?	2920.69	------	1	II
2467.68	------	2	II	2624.58	------	1	II	2923.37	------	1	II
2469.27	10	40	II	2633.72	------	2	II	2931.53	7*h*	------	I
2470.27	------	1	II	2634.75	------	1	II	2939.08	------	2*h*	II
2470.81	------	1	II	2644.56	------	2*h*	II	2946.39	------	2*h*	II
2472.50	------	2*h*	II	2652.48	------	1	II	2949.73	20*h*	1	I
2475.34	------	3	II	2653.34	------	2*h*	II	2951.69	20	80	II
2481.72	20	100	II	2657.80	50	150	II	2955.78	2	60*hl*	II
2487.96	------	4	II	2660.46	------	2	II	2960.10	------	2*h*	II
2488.28	------	1	II	2670.78	5*h*	------	I	2963.32	50	150	II
2489.24	------	2	II	2677.25	10*h*	------	I	2969.82	30	100	II
2489.83	------	2	II	2677.77	1	10*h*	II	2975.67	------	1	II
2493.84	------	2	II	2685.08	50*h*	3	I	2978.50	------	1	II
2494.64	------	6	II	2685.54	10*h*	1	I	2985.85	------	3*h* Yb?	II
2495.08	------	1	II	2688.09	------	2	II	2989.27	50	4	I
2495.52	------	2	II	2692.34	5*h*	------	I	2992.48	------	1	II
2495.86	------	1	II	2696.95	------	2	II	2995.84	------	15*hl*	II
2496.83	------	2	II	2697.45	------	2	II	3003.65	------	3*h*	II
2497.83	------	2	II	2699.74	------	3	II	3016.37	------	15*hl*	II
2498.99	------	3	II	2701.71	40	150	II	3020.54	40	100	II
2500.23	------	1*h*	II	2703.13	7*h*	------	I	3027.29	4	8	II
2500.86	5*h*	1	I	2707.66	------	1	II	3040.04	------	20*hl*	II
2509.04	------	3 Tm?	II	2715.38	------	1	II	3044.18	------	1	II
2511.37	------	1	II	2715.91	4*h*	------	I	3047.36	3*h*	------	I
2512.87	------	2	II	2719.09	10*h*	?	I	3055.70	1	2	II
2513.99	------	1	II	2724.81	------	4	II	3056.72	50	100	II
2514.41	------	1	II	2728.95	40	2	I	3057.90	3*e*	150*h*	III
2518.04	------	4	II	2738.17	2	25*hl*	II	3062.65	------	2*h*	II
2518.77	------	1	II	2749.70	------	2*hd*?	II	3063.51	20*h*	------	I
2519.05	------	1	II	2754.17	40	120	II	3067.83	------	3*h*	II
2520.53	------	2	II	2765.74	20	3	I	3077.60	100	200	II
2523.27	------	1	II	2772.58	5*e*	150*h*	III	3080.11	15	2	I
2526.83	1	10*h*	II	2778.52	------	1	II	3081.47	80	8	I
2528.59	------	5*h*	II	2781.47	4*h*	------	I	3089.02	------	8*h*	II
2529.84	------	1	II	2784.80	------	8*h*	II	3101.99	------	4*hl*	II
2530.55	------	8*h*	II	2785.70	------	1	II	3104.98	------	25*hl*	II
2534.74	------	2	II	2787.44	------	1	II	3115.32	2	1	I?
2536.95	10	20	II	2796.63	25	100	II	3118.43	40	5	I
2538.12	------	3 Yb?	II	2817.95	------	1	II	3161.62	------	10*hl*	II
2539.41	------	1	II	2819.50	------	6*hl*	II	3167.33	1	15*hl*	II
2542.35	2	?	I?	2821.23	2*e*	50*hl*	III?	3171.36	40	5	I
2546.32	------	5*h*	II	2826.82	------	6*hl*	II	3180.27	------	1*h*	II
2546.87	------	9*h*	II	2828.95	------	1	II	3183.73	3	6	II
2548.63	------	10*h*	II	2829.42	------	3*h*	II	3191.80	3	60*hl*	II
2549.52	20*h*	------	I	2830.79	------	1	II	3198.12	40	80	II
2550.67	------	3	II	2834.35	5	40*h*	II	3214.31	------	1 Yb?	II

See footnotes at end of table.

TABLE 2.—*Arc and spark spectra of lutecium* (*Z*=71)—Continued

λair A	Intensity and character		Spectrum	λair A	Intensity and character		Spectrum	λair A	Intensity and character		Spectrum
	Arc	Spark			Arc	Spark			Arc	Spark	
3219.09	-------	3*h*	II	3829.07	10*h*	-------	I	4521.08	2*h*	-------	I
3222.57	-------	8*h*	II	3841.18	100	8	I	4525.48	2*h*	-------	I
3242.93	-------	4*h*	II	3843.61	15*h*	-------	I	4533.39	5*B*?	-------	LuO?
3245.93	-------	2*h*	II	3853.29	10	-------	I	4553.47	2*p*?	-------	I
3246.71	-------	2*h*	II	3870.88	5	-------	I	4560.95	8*Bl*	-------	LuO
3249.47	-------	4	II	3874.61	4	-------	I	4569.5	5*Bl*	-------	LuO
3251.95	-------	1*h*	II	3876.65	50c	100c	II	4575.31	5*Bl*	-------	LuO
3254.31	50	150	II	3888.38	-------	1*h*	II	4585.17	1*p*?	-------	I
3265.00	-------	10*hl*	II	3899.54	-------	3*h*	II	4586.93	2	6	II
3265.62	2	-------	I	3911.77	3*h*	-------	I	4590.68	3*B*?	-------	LuO?
3278.97	50	5	I	3918.86	4	-------	I	4602.04	1*p*?	-------	I
3280.50	10	-------	I	3925.30	20	1	I	4602.60	3*h*	-------	I
3281.74	60	5	I	3926.62	2	-------	I	4605.39	10*h*	-------	I
3303.75	-------	1*h*	II	3937.61	-------	5*hl*	II	4643.29	8*h*	-------	I
3305.68	2	? Yb?	I?	3968.46	50?	? Ca+	I	4645.47	25*h*	2	I
3312.11	100	10	I	3981.01	-------	2*h*	II	4648.21	25*h*	2	I
3319.63	-------	3*h*	II	3991.38	3	-------	I	4648.85	25*h*	?	I
3332.61	-------	8*h*	II	4030.86	-------	5*hl*	II	4651.94	2*p*?	-------	I
3338.62	-------	1	II	4033.02	4 Ga?	-------	I	4654.03	15*Bl*	-------	LuO
3359.56	150	15	I	4064.45	25	3	I	4656.49	2*p*?	-------	I
3364.26	-------	1	II	4079.87	1*h*	-------	I	4658.02	100	15	I
3376.50	100	10	I	4094.04	10B*l*	-------	LuO	4659.03	10	1	I
3385.50	30	4	I	4096.13	20B*l*	-------	LuO	4661.75	150*Bl*	15*Bl*	LuO
3391.55	10	2	I	4107.44	3*p*?	-------	I	4672.31	120*Bl*	12*Bl*	LuO
3396.82	30	1	I	4112.67	5	-------	I	4675.29	4*p*?	-------	I
3397.07	50	200	II	4122.49	15	2	I	4684.16	100*Bl*	10*Bl*	LuO
3418.42	3 Yb?	-------	I	4124.73	200	10	I	4689.77	4+*p*	-------	I
3423.30	-------	1*h*	II	4131.79	10+*p*	-------	I	4695.46	80*Bl*	8*Bl*	LuO
3454.77	-------	3*h*	II	4154.08	40	3	I	4708.00	60*Bl*	6*Bl*	LuO
3472.48	50	150	II	4158.98	1	-------	I	4716.70	5	-------	I
3491.92	-------	3*h*	II	4167.50	2	-------	I	4720.86	5*B*	-------	LuO
3507.39	100*c*	150	II	4184.25	100	200	II	4726.20	4*p*?	-------	I
3508.42	30	3	I	4223.09	1	4	II	4733.50	-------	3*h*	II
3518.89	1	-------	I	4223.99	2	-------	I	4735.00	25*Bl*	2	LuO
3521.18	3	-------	I	4235.51	1	-------	I	4748.38	-------	10*hl*	II
3525.94	2	-------	I	4239.30	5 B*l*?	-------	LuO	4749.11	10*Bl*	1	LuO
3546.39	7	-------	I	4241.9	10*Bl*	-------	LuO	4757.26	1*p*?	-------	I
3553.10	2	-------	I	4252.53	5*B*?	? Yb+	LuO	4764.22	7*Bl*	1	LuO
3554.43	50	150	II	4262.02	-------	8	II	4774.05	1*p*?	-------	I
3567.84	100	7	I	4266.40	-------	2*h*	II	4779.00	1 Yb?	-------	I
3580.26	3	-------	I	4277.50	30	3	I	4780.11	5*B*	-------	LuO
3596.34	6	-------	I	4281.03	40	4	I	4785.42	100	200	II
3620.31	4	-------	I	4295.97	30	3	I	4798.00	3*B*	-------	LuO
3623.99	20	40	II	4296.09	15	2	I	4810.52	2 Zn?	-------	I
3628.90	2	-------	I	4309.57	25	2	I	4815.05	20	2	I
3636.25	25	3	I	4332.72	10	1	I	4839.62[b]	50*c*	100*c*	II
3642.35	2?	-------	I	4341.98	3	30*hl*	II	4843.03	2	5	II
3647.77	100	5	I	4355.05	3	-------	I	4844.44	3	-------	I
3678.04	-------	3*h*	II	4374.90	5	-------	I	4858.75	2	8	II
3682.40	1?	-------	I	4396.16	2	?	I?	4860.15	1*h*	-------	I
3684.32	15	1	I	4397.31	7	-------	I	4864.52	1*h*	-------	I
3704.79	-------	3*h*	II	4404.86	5?	-------	I	4865.36	4	20	II
3706.16	2	-------	I	4416.45	6	-------	I	4870.78	1*h*	-------	I
3710.95	3	-------	I	4420.96	15*c*	-------	I	4882.40	3*h*	-------	I
3722.58	3?	-------	I	4430.48	30*c*	2	I	4888.14	2*h*	-------	I
3724.32	2*h*?	-------	I	4438.79	4	-------	I	4895.00	1*h*	-------	I
3742.08	2	-------	I	4450.81	40	2	I	4904.88	60	5	I
3756.70	8	-------	I	4471.55	7	-------	I	4907.16	1*h*	-------	I
3756.79	6	-------	I	4480.15	3	-------	I	4911.41	1	-------	I
3777.15	-------	2*h*	II	4490.53	2	-------	I	4921.70	3	8	II
3786.18	4	-------	I	4498.85	10	1	I	4942.34	40	3	I
3793.24	4	-------	I	4505.22	1	5	II	4976.92	1*h*	-------	I
3800.67	5	-------	I	4508.91	5*B*?	-------	LuO	4994.13[c]	250*c*	400*c*	II
3802.62	3	-------	I	4517.71	1*h*	-------	I	5001.14	100	?	I
3814.02	2	-------	I	4518.57	300*c*	40	I	5057.60	15	1	I

See footnotes at end of table.

TABLE 2.—*Arc and spark spectra of lutecium (Z=71)*—Continued

λ~air~ A	Intensity and character		Spectrum	λ~air~ A	Intensity and character		Spectrum	λ~air~ A	Intensity and character		Spectrum
	Arc	Spark			Arc	Spark			Arc	Spark	
5134.05	20	2	I	6365.90[h]	25*d*	--------	I	8082.36	2	--------	I
5135.09	200	20	I	6441.14	40*c*	--------	I	8178.16	40*c*	--------	I
5161.06	4*Bl*	--------	LuO	6444.89	5	15	II	8248.68	2	--------	I
5170.11	10*Bl*	--------	LuO	6463.12[i]	400*c*	800	II	8329.45	5	--------	I
5196.61	10+*p*	--------	I	6477.67	30	2	I	8382.08	30	--------	I
5206.47	10	--------	I	6523.18	80*c*	5	I	8408.21	8	--------	I
5250.71	2*p*?	--------	I	6611.7[j]	100*c*	150*c*	II	8459.19	150	--------	II
5278.48	--------	2*h*	II	6619.15	5	--------	I	8478.50	50	--------	I
5304.40	20	2	I	6668.74	4*c*	--------	I	8508.08	100	--------	I
5349.12	25	2	I	6677.14	40	1	I	8610.98	120	--------	I
5402.57[d]	150*c*	10*c*	I	6735.76	5	--------	I	8690.23	3*h*	--------	I
5421.90	50*c*	5	I	6766.32	2*h*?	--------	I	8712.78	3	--------	II
5437.88	30	3	I	6793.77	40*c*	2	I	8719.00	1*e*	--------	I
5453.57	8	1	I	6826.59	4	--------	II	8744.03	3*e*	--------	I
5465.50	3?	--------	I	6892.55	3	--------	II	8788.83	4*e*	--------	I
5476.69[e]	500	1000	II	6917.31	50	--------	I	8795.6	2	--------	I
5505.91	1	--------	I	6943.96	5	--------	I	8949.5[m]	40*c*	--------	II
5602.56	1	5	II	7031.24	50	--------	I	9116.26	20*e*	--------	I
5664.89	2	20	II	7096.34	30*c*	--------	I	9203.92	8*c*	--------	I
5713.49	3	15	II	7101.98	2?	--------	I	9273.79	2*e*	--------	I
5736.55	150*c*	15	I	7125.84	120	--------	II	9282.5	1?	--------	I
5775.40	50	5	I	7142.79	7	--------	I	9504.50	2*e*	--------	I
5800.59	30	5	I	7143.10	5	--------	I	9661.69	10*e*	--------	II
5860.79	20*c*	2	I	7165.94	9	--------	II?	9696.03	30*e*	--------	I
5866.30	3	--------	I	7196.40	5*c*	--------	I	9841.32	2	--------	II
5887.23	1	6*h*	II	7229.06	2?	--------	I	9892.00	5*e*	--------	I
5961.39	3*c*	--------	I	7237.98	40*c*	--------	I	9909.9	1*e*?	--------	I
5983.9[f]	200*c*	400*c*	II	7324.97	2?	--------	I	9914.92	100*e*	--------	I
5997.13	50	5	I	7409.70	7	--------	II	10012.46	5*c*	--------	I
6004.52	400	40	I	7441.52	20	--------	I	10114.8	2*e*	--------	I
6041.66	20*c*	1	I	7456.96	5	--------	II	10118.54	4*e*	--------	I
6055.03	150*d*	10	I	7543.06	2	--------	I	10282.26	10*e*	--------	I
6084.14	15*c*	--------	I	7553.20	1	--------	I	10497.6	6	--------	I
6140.71	10*c*	--------	I	7640.08	9	--------	I	10680.5	8	--------	I
6141.72	5	--------	I	7649.54[k]	8*c*	--------	I	10729.8	10	--------	I
6159.94	50	200	II	7659.01	4*c*	--------	I	10758.2	5	--------	II
6195.12	15*c*	--------	I	7686.81	2*h*	--------	I	10770.2	20	--------	I
6199.66	40	120	II	7758.30	20*c*	--------	I				
6221.87[g]	500	1000	II	7815.9[l]	25*c*	--------	I				
6228.14	10	40	II	7911.62	30*c*	--------	I				
6235.36	25	100	II	7912.32	3?	--------	I				
6242.34	40	200	II	7917.52	15	--------	II				
6248.80	10*c*	--------	I	7927.58	2?	--------	I				
6345.35	60	4	I	7939.63	2	--------	I				
6354.85	20	1	I	7965.31	10*c*	--------	I				

[a] Measured double in arc {2603.28 (5). 2603.39 (5).

[b] Nine components according to Schüler and Schmidt [16].

[c] Thirteen components according to Schüler and Schmidt [16].

[d] Fifteen components according to Gollnow [17].

[e] Fifteen components according to Schüler and Schmidt [16].

[f] Seven components according to Schüler and Schmidt [16].

[g] Nine components according to Schüler and Schmidt [16].

[h] Measured double {6365.79 (10). 6366.00 (15).

[i] Three components according to Schüler and Schmidt [16].

[j] Five components measured {6611.28 (30). 6611.58 (25). 6611.80 (20). 6611.95 (15). 6612.04 (10).

[k] Diffuse double measured {7649.28 (3). 7649.79 (3).

[l] Unsymmetrical double measured {7815.84 (15). 7816.14 (6).

[m] Three components measured {8948.93 (20). 8949.63 (15). 8950.18 (10).

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WASHINGTON, May 5, 1937.