The Normal Electron Configuration of Singly Ionized Gadolinium

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The normal electron configuration of singly ionized gadolinium is established as $4f^7 5d6s$. The quantum numbers of the energy levels are deduced from a study of Zeeman effect patterns obtained with a field of 81,500 gauss.

INTRODUCTION

THE normal electron configuration of gadolinium is known to be $4f^7 5d6s^2$.[1] On ionization, one would expect either the $5d$ or a $6s$ electron to be removed. There is also the possibility of the $4f$ shell becoming relatively more stable on ionization, enabling the capture of an electron to give a configuration of $4f^8 6s$ or $4f^8 5d$. In the cases of samarium[2] and europium,[3] a $6s$ electron is removed on ionization of the neutral atom.

Many violations of the Hund rule for the lowest term of an electron configuration are known for excited electron configurations, but no violation has yet been found among the hundreds of normal electron configurations that are now known. According to the Hund rule, the four most likely normal electron configurations of Gd II should yield the following for the lowest terms:

$4f^7 5d6s - {}^{10}D, {}^8D, {}^8D, {}^6D,$
$4f^7 6s^2 \quad - {}^8S,$
$4f^8 6s \quad - {}^8F, {}^6F,$
$4f^8 5d \quad - {}^8H, {}^8G, {}^8F, {}^8D, {}^8P, {}^6H, {}^6G, {}^6F, {}^6D, {}^6P.$

Accordingly, the lowest term of Gd II should be one of ${}^{10}D$, ${}^8S$, ${}^8F$ or ${}^8H$. It should be noted that $4f^7 5d6s$ (the one expected to be normal by analogy with samarium and europium) is the only one that gives a decet term, namely a lone ${}^{10}D$.

EXPERIMENTAL

The senior author had been engaged for some time in a fruitless attempt to discover the normal electron configuration of Gd II, when the large Bitter magnet[4] was installed in the spectroscopy laboratory of this institute. At the same time Dr. A. S. King at the Mount Wilson Observatory in Pasadena made available to us his most recent furnace temperature classification of lines of the gadolinium spectrum.[5]

Electrodes composed of a silver-gadolinium mixture were prepared by first pressing and then sintering a silver powder-gadolinium salt mixture. We are indebted to Professor John Wulff for their preparation. With these electrodes, Zeeman effect photographs were obtained with

TABLE I. *Calculated and observed Landé g values in* Gd II.

Term Type	J Value	g value Cal.	g value Obs.
$a^{10}D°$	2½	2.57	2.57
	3½	2.10	2.10
	4½	1.88	1.88
$z^{10}F$	1½	3.20	3.13
	2½	2.23	2.17
	3½	1.90	1.86
	4½	1.76	1.79

TABLE II. *Energy levels in* Gd II.

Term Type	J Value	Energy cm⁻¹	Term Type	J Value	Energy cm⁻¹
$a^{10}D°$	2½	0.00	$z^{10}F$	1½	25,960.08
	3½	261.87		2½	26,211.92
	4½	633.28		3½	26,595.22
	5½	1158.95		4½	27,162.22
	6½	1935.31		5½	27,864.50
				6½	29,353.33
$a^8D°$	2½	3082.02	$z^{10}D$	2½	28,629.02
	3½	4483.89		3½	29,242.22
	4½	4852.36		4½	30,027.39
	5½	4841.14		5½	30,101.36
				6½	32,946.23

[1] W. E. Albertson, Phys. Rev. **47**, 370 (1935).
[2] W. E. Albertson, Phys. Rev. **52**, 644 (1937); Astrophys. J. **84**, 26 (1936).
[3] W. E. Albertson, Phys. Rev. **45**, 499 (1934); H. N. Russell and A. S. King, Astrophys. J. **90**, 155 (1939).
[4] F. Bitter, Rev. Sci. Inst. **7**, 479 (1936); G. R. Harrison and F. Bitter, Phys. Rev. **57**, 15 (1940).
[5] A. S. King, unpublished material.

TABLE III. *Multiplets in* Gd II.

WAVE-LENGTH I.A.	WAVE NUMBER CM^{-1}	INTENSITY	COMBINATION
			$a^{10}D°-z^{10}F$
3759.011	26,595.21	40	$2\frac{1}{2}-3\frac{1}{2}$
3716.369	26,900.36	80	$3\frac{1}{2}-4\frac{1}{2}$
3671.216	27,231.20	200	$4\frac{1}{2}-5\frac{1}{2}$
3545.794	28,194.41	200	$5\frac{1}{2}-6\frac{1}{2}$
3813.981	26,211.91	200	$2\frac{1}{2}-2\frac{1}{2}$
3796.393	26,333.34	200	$3\frac{1}{2}-3\frac{1}{2}$
3768.405	26,528.93	100	$4\frac{1}{2}-4\frac{1}{2}$
3743.484	26,705.52	200	$5\frac{1}{2}-5\frac{1}{2}$
3646.196	27,418.06	300	$6\frac{1}{2}-6\frac{1}{2}$
3850.981	25,960.07	200	$2\frac{1}{2}-1\frac{1}{2}$
3852.467	25,950.06	150	$3\frac{1}{2}-2\frac{1}{2}$
3850.703	25,961.95	150	$4\frac{1}{2}-3\frac{1}{2}$
3844.584	26,003.27	125	$5\frac{1}{2}-4\frac{1}{2}$
3855.581	25,929.10	20	$6\frac{1}{2}-5\frac{1}{2}$
			$a^{8}D°-z^{10}F$
4251.741	23,513.18	300	$2\frac{1}{2}-3\frac{1}{2}$
4408.261	22,678.33	80	$3\frac{1}{2}-4\frac{1}{2}$
4344.313	23,012.15	20	$4\frac{1}{2}-5\frac{1}{2}$
4078.465	24,512.13	150	$5\frac{1}{2}-6\frac{1}{2}$
4322.195	23,129.91	20	$2\frac{1}{2}-2\frac{1}{2}$
4521.303	22,111.34	12	$3\frac{1}{2}-3\frac{1}{2}$
4481.068	22,309.87	100	$4\frac{1}{2}-4\frac{1}{2}$
4342.191	23,023.40	300	$5\frac{1}{2}-5\frac{1}{2}$
4369.775	22,878.07	80	$2\frac{1}{2}-1\frac{1}{2}$
4601.067	21,728.02	100	$3\frac{1}{2}-2\frac{1}{2}$
4597.922	21,742.88	100	$4\frac{1}{2}-3\frac{1}{2}$
4478.812	22,321.11	80	$5\frac{1}{2}-4\frac{1}{2}$

WAVE-LENGTH I.A.	WAVE NUMBER CM^{-1}	INTENSITY	COMBINATION
			$a^{10}D°-z^{10}D$
3418.735	29,242.23	150	$2\frac{1}{2}-3\frac{1}{2}$
3358.628	29,765.54	150	$3\frac{1}{2}-4\frac{1}{2}$
3392.534	29,468.06	80	$4\frac{1}{2}-5\frac{1}{2}$
3145.006	31,787.26	100	$5\frac{1}{2}-6\frac{1}{2}$
3491.967	28,628.99	100	$2\frac{1}{2}-2\frac{1}{2}$
3449.628	28,980.36	40	$3\frac{1}{2}-3\frac{1}{2}$
3401.060	29,394.19	20	$4\frac{1}{2}-4\frac{1}{2}$
3454.149	28,942.43	40	$5\frac{1}{2}-5\frac{1}{2}$
3223.740	31,010.95	40	$6\frac{1}{2}-6\frac{1}{2}$
3524.21	28,367.07	80	$3\frac{1}{2}-2\frac{1}{2}$
3494.418	28,608.91	100	$4\frac{1}{2}-3\frac{1}{2}$
3462.99	28,868.54	40	$5\frac{1}{2}-4\frac{1}{2}$
3549.365	28,166.04	200	$6\frac{1}{2}-5\frac{1}{2}$
			$a^{8}D°-z^{10}D$
3913.79	25,543.47	6	$3\frac{1}{2}-4\frac{1}{2}$
3959.437	25,249.00	30	$4\frac{1}{2}-5\frac{1}{2}$
3557.062	28,105.09	80	$5\frac{1}{2}-6\frac{1}{2}$
4037.906	24,758.34	125	$3\frac{1}{2}-3\frac{1}{2}$
3971.077	25,174.99	20	$4\frac{1}{2}-4\frac{1}{2}$
3957.681	25,260.20	150	$5\frac{1}{2}-5\frac{1}{2}$
4140.454	24,145.16	12	$3\frac{1}{2}-2\frac{1}{2}$
4098.912	24,389.86	80	$4\frac{1}{2}-3\frac{1}{2}$
3969.28	25,186.39	40	$5\frac{1}{2}-4\frac{1}{2}$

a field of 81,500 gauss at a dispersion of 0.8A/mm throughout the range λλ2400–3900A. Although the gadolinium lines were fairly faint, several lines were completely resolved, with all of their Zeeman effect components showing, enabling the unique determination of both the J values and g values of the levels involved.

RESULTS

A term array was discovered which accounted for all of the low and nearly all of the middle temperature class Gd II lines. All of the low temperature lines were classified in a single multiplet ^{10}DF, of which the ^{10}D was the lowest term in the array. The quantum numbers of this term are established beyond a doubt, the J values by counting the number of components of the resolved patterns, and the L and S values from the excellent agreement between experimental and Landé g values, as is shown in Table I. The fact that all of the fundamental lines of the spectrum are now classified casts serious doubt on the proposition that levels lower than those of the ^{10}D exist. From arguments stated above, it is clear that $4f^75d6s$ is the normal electron configuration of Gd II. Of the other terms from this configuration, fragments of the two ^8D terms have been found. The excitation of the $6s$ to a $6p$ electron gives the electron configuration $4f^75d6p$, which yields the triads ^{10}FDP, ^8FDP, ^8FDP, ^6FDP. Of these, the ^{10}F and ^{10}D terms are definitely established, as well as numerous unidentified levels.

The energy levels are given in Table II, and the multiplets in Table III. The wave-length measurements are taken from the M.I.T.-W.P.A. Wavelength Tables.[6] The temperature classifications are from King.[7]

CONCLUSION

In addition to those already acknowledged, we wish to thank Professor G. R. Harrison for the Zeeman effect photographs and for making wave-length data available to us previous to publication.

[6] G. R. Harrison, *Wavelength Tables* (Wiley & Sons, 1939.)

[7] A. S. King, Astrophys. J. **72**, 221 (1930).