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*HYPER-FINE STRUCTURE IN SPECTRAL LINES—ESPECIALLY THOSE OF SINGLY IONIZED PRASEODYMIUM**

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Fine structure in spectral lines has been reported from time to time for a few lines in each of several elements. In the majority of cases this complexity has been observed in the case of lines arising from the neutral atom, though a few lines, identified as belonging to the spectra of singly ionized helium, aluminum and lanthanum, have also been found to consist of two or more components. So far as we are aware no line definitely identified as belonging to the spectra of an element in a stage of ionization higher than the first has been reported as having more than a single component. This can hardly be taken to mean necessarily that lines radiated by atoms in the higher states of ionization are, on the whole, simpler than those in the arc and first spark spectra. The spectra of highly ionized atoms are comparatively difficult to produce and many of the stronger lines are found in regions of the spectrum where high dispersion apparatus cannot be so readily utilized. All but the more recent observations of complex structure are mentioned and discussed in reports by Ruark[1] and Chenault,[2] and by Meggers and Burns.[3] Bach and Goudsmit[4] used very high precision apparatus in studying the Zeeman effect upon certain hyper-fine lines of bismuth. McNair[5] has studied the Zeeman patterns of the hyper-fine lines in the 2537 line of mercury. Schuler[6] has observed close components in certain lines of lithium and in the *D* lines of sodium. King[7] in making a careful study and classification of lines in the spectra of praseodymium has pointed out the complex structure of many of these lines, the vast majority of which are believed to belong to the first spark spectrum. Very recently King[8] has reported the existence of hyper-fine structure in lines from several other rare-earth elements.

In most cases of hyper-fine structure the number of components found is not the same for the various complex lines of any one element. In King's[7] list of praseodymium lines the components for complex lines range in number from two to six with many in doubt because of the lack of sufficient dispersion to separate the components distinctly. His observations were taken chiefly from plates made in the second order spectrum of a 15-foot grating having about 15,000 lines to the inch. Last summer photographs of the emission lines from a carbon arc cored with praseodymium oxalate, most of the strong lines of which according to King's classification are those from singly ionized atoms, were made by one of us over the region 3900 to 5000 Angstroms, using the fourth-order spectrum of the 75-foot solar spectrograph on Mt. Wilson, the grating of which has about 15,000 lines to the inch. A dispersion of about 1.5 Angstroms per centimeter was obtained and the complex structures of many lines were clearly resolved. Within the region studied all of the completely resolved fine structures consist of six components. In order to bring out as many lines as possible with a single exposure a rather wide slit was used and fairly long exposures were made. Consequently, some of those lines that have relatively small dispersion between their components are too blurred on the plates to enable the number of components to be accurately determined. Other lines with slightly greater separations reveal definitely the number of components but the separations of their closer components cannot be measured with precision. Of the nearly 200 lines within the above-mentioned region that exhibit a complex structure 33 lines have been studied and their component separations carefully measured. The results are shown in table 1. The size of the dispersion for any region was determined from solar absorption lines photographed contiguously on the same plate, while wave-lengths were determined from single or very sharp lines of praseodymium as listed by King.

The components of some lines show decreasing intervals and intensities toward shorter wave-lengths while others are similarly degraded toward longer wave-lengths. This fact is indicated in table 1 by giving in column 2 the wave-length of the component of strongest intensity which is either the component of maximum wave-length or of minimum wave-length according to the direction in which the components are degraded, and by listing in column 4 the separations of the components in hundredths of $cm.^{-1}$, arranged in the order of progression from the strongest component. These lines can be classified roughly according to the separations of their components into three groups. This classification is indicated in the table by a step-wise displacement of the separations in column 4 and by the three sub-columns of total separation values in column 5. At the bottom of the table the maximum variation in corresponding separations is shown for lines that are grouped together. It is difficult to say how

TABLE I

λ KING'S LIST	λ MAX.	ν	CM.$^{-1}$ × 10^2 Δν									TOTAL Δν CM.$^{-1}$ × 10^2		
4449.87	4449.93	22472.26	24	21	18	16	12					91		
4454.39	4454.46	22449.41	24	21	19	15	12					91		
4458.33	4458.40	22429.57	25	24	22	19	16					106		
4477.27	4477.36	22334.59			29	26	22	19	16				112	
4494.20	4494.37	22250.06					39	35	29	23	20			146
	4606.53	21708.31	26	22	23	18	16					105		
4628.75	4628.85	21603.64			36	30	25	20	18				129	
4643.51	4643.60	21535.02			33	29	24	22	16				124	
4651.51	4651.60	21497.98	26	23	20	19	13					101		
4684.93	4685.07	21344.40			32	26	22	20	14				114	
4704.52	4707.61	21242.20	23	20	20	16	12					91		
4707.97, 4708.17	4708.21	21239.49					41	36	31	23	20			151
	4726.53	21157.17			32	27	23	19	17				118	
4734.17	4734.28	21122.54	22	20	19	16	13					90		
4744.93	4745.07	21074.50	25	22	20	16	13					96		
4756.13	4756.22	21025.10					40	34	29	23	19			145
4758.05	4758.06	21016.97			31	27	24	19	17				118	
4765.22	4765.35	20984.82			28	25	22	21	19				115	
	4778.42	20927.42			34	31	26	22	18				131	
	4801.23	20829.00	28	24	19	18	13					102		
4832.09	4832.17	20694.64			30	27	22	19	14				112	
4837.02	4837.13	20673.42	26	23	21	19	15					104		
4848.52	4848.65	20624.30			30	27	23	19	12				111	
	4891.26	20444.63			33	28	25	23	19				128	

λ KING'S LIST	λ MIN.	ν	CM.$^{-1}$ × 10^2 Δν									TOTAL Δν CM.$^{-1}$ × 10^2		
4438.17	4438.12	22532.06	22	19	18	16	13					88		
4450.24	4450.13	22471.25	26	23	21	19	16					105		
4465.98	4465.87	22392.05	27	23	21	14	11					96		
4468.70	4468.56	22378.57	23	22	20	17	10					92		
4746.94	4746.87	21066.51	26	22	20	18	15					101		
	4808.44	20796.77					35	35	32	28	19			149
4822.98	4822.87	20734.54	22	19	15	14	13					83		
	4826.58	20718.60	27	24	20	18	17					106		
4877.81	4877.68	20501.55			31	28	26	21	18				124	
			22	19	15	14	10					83	111	145
			28	24	23	19	17					106	131	151
Variation of Δv					28	25	22	19	12					
					36	31	26	23	19					
							35	34	29	23	19			
							41	36	32	28	20			

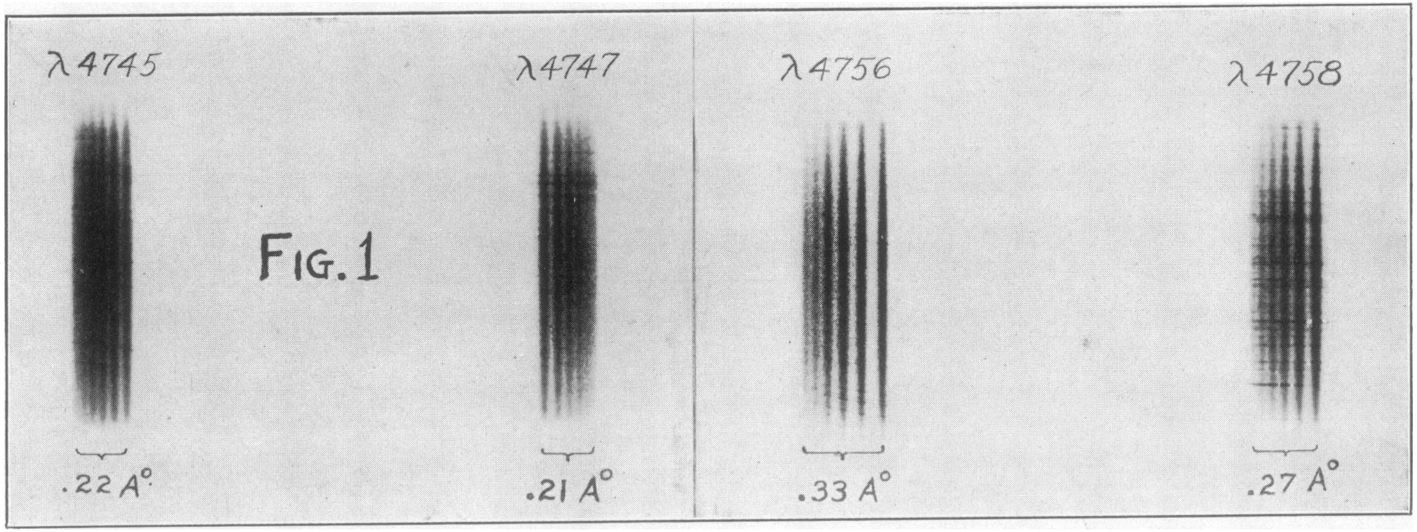

FIG. 1

much significance, if any, should be attached to this classification. Further study of these lines with sharper photographs and of additional lines may indicate the possibility of a finer and more extended grouping. Such more precise groupings, if found possible, will doubtless assist in arranging the composite lines into ordinary multiplets and in recognizing the way in which the terms of these multiplets are split up to form fine structure terms. Further study and experimentation with this end in view is contemplated. Doubtless Zeeman patterns of some of these lines will be helpful in this connection. A somewhat enlarged reproduction of the photograph of four of the lines studied is shown in figure 1. This gives a fairly good picture of how these lines look. From the figure and the table it is seen that the frequency intervals between the components of any one line follow very closely the Landé[1] interval rule, and that the relative intensities of the components decrease with the interval. All of the lines for which detailed data are given are listed by King as belonging to the spectrum of singly ionized atoms.

It has been suggested by other investigators that the splitting up of ordinary energy levels into fine structure sub-levels might be attributed to the nucleus of an atom having a resultant angular momentum and hence a magnetic moment. This assignment of a magnetic moment to the nucleus rather than to electrons in the external shell of the atom is due to the fact that the separations between sub-levels is extremely small as compared with the splitting up due to various couplings between external electrons.

Bach and Goudsmit[4] were in one case able to assign an angular momentum of $9/2 \cdot h/2\pi$ to the nucleus of bismuth. In order to account for the fine structure in Pr II, as shown in the figure, an angular momentum of $5/2 \cdot h/2\pi$ should be assigned to the once-ionized atom of praseodymium. This angular momentum space-quantized with the resultant angular momentum of the external electrons would cause each multiple energy level to be broken up into six components. Under such conditions an electron transition may, apparently, take place in at least six different ways, where as before it could take place in only one way.

The assignment of quantum numbers to each of the six sub-levels of the initial state and also the six sub-levels of the final state should under the ordinary selection principles yield as many as fifteen or sixteen radiated lines. Normally we should expect six of these lines to be intense lines with the remaining nine or ten lines somewhat weaker. If the sub-levels of both the initial and final states follow the "Lande Interval Rule," as we would expect, then the six strong lines should reveal intensities and relative separations exactly as shown in the photographs. Since the other nine or ten lines, as the case may be, have not yet been observed, we may say that they are either very weak or that they do not occur.

The latter is in contradiction with the results found in lanthanum and in bismuth.

In order to account for only six lines an attempt has been made to assign three sub-levels to the initial and final states. Although the relative intensities and separations are about what one should expect in certain cases, the frequency separations definitely show that this cannot be the explanation.

In conclusion we wish to express our appreciation of the many favors shown us by various members of the Mt. Wilson Observatory Staff and to acknowledge the invaluable assistance rendered us by the facilities that they so generously placed at our disposal.

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A METHOD OF PRODUCING LONG SINGLE-CRYSTALS OF METAL AND A STUDY OF THE FACTORS INFLUENCING CRYSTAL-ORIENTATION AND PERFECTION

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The apparatus described in the following was to serve the purpose of studying the influence on the orientation of the gradient of temperature along a single crystal during its growth, and the effect of strong magnetic fields applied at the exact point of transition of the two phases of the metal. It was found that the particular method of growing crystals of great length, developed for this investigation, was superior to any others known to the authors. It became evident that the influence of a magnetic field applied to a zone of crystallization is of such complexity that it seemed to be better to describe these effects in a separate paper, especially since the method has practically nothing to do with the special purpose, and therefore, may be of more general interest.