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THE APPLICATION OF WAVELENGTH COINCIDENCE STATISTICS TO LINE IDENTIFICATION: HR 465 AND HR 7575

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ABSTRACT

A Monte Carlo technique for the experimental determination of probabilities has been used to supplement standard line-identification procedures in the Ap stars HR 465 and HR 7575. The resulting identifications are divided into three categories ranging from definite to possible identifications. The identification of U II and Pt II in HR 465, the possible identification of Te II, Os II, and Pm II in HR 465, and the possible identification of Se II and Cs II in HR 7575 are discussed in more detail. It is suggested that HR 465 has some of the properties usually associated with both the Hg-Mn and the Cr-Eu stars.

Subject headings: abundances, stellar — line identifications — peculiar A stars — stars, individual

I. INTRODUCTION

Standard stellar line-identification procedures are based on wavelength coincidences and a comparison of the intensities and character of the lines in the laboratory and stellar spectrum. Recently, Tech (1971) has given a penetrating discussion of this problem in which he introduces laboratory gf-values as an additional tool for line identification work. In a number of circumstances of great astrophysical interest it is desirable to *supplement* the standard techniques by additional procedures which we shall discuss.

The question of the presence of promethium in the 1960–1964 spectrum of the Ap star HR 465 illustrates the basic need for new identification techniques. Aller and Cowley (1970) pointed out that there were features in the stellar spectrum close to the laboratory wavelengths of all of the strong lines. They suggested (cf. Cowley and Aller 1972) that severe blending and hyperfine structure would make it difficult to establish intensity correlations and could also account for the poor agreement between the laboratory and stellar wavelengths. In these circumstances it is difficult to formulate an objective judgment of the identification under consideration.

Russell and Bowen (1929) presented a simple formula for calculating the expected number of chance coincidences between a set of laboratory and measured stellar wavelength lists under the assumption that the stellar lines are distributed randomly in the list. The formula was used by Aller and Cowley (1970). However, this assumption is difficult to justify in general, and it has been shown to be false in the case of the HR 465 list by Cowley and Aller (1972) and Havnes and van den Heuvel (1972). These workers substituted a random trial method for the Russell-Bowen formula. We have essentially adopted this technique, but have increased the number of trials as will be discussed in § II.

II. THE COINCIDENCE TESTS

The method we have adopted to determine the statistical significance of an identification is a simple, straightforward procedure. We search for a set of laboratory

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wavelengths of the element in question on the stellar wavelength list within a tolerance, $\pm w$. We then make up sets of control or nonsense wavelengths. In this present work we have generally used 100 control sets; however, as many as 10,000 control sets have been used in special cases. Each of these sets has the same number of lines as the laboratory set and is prepared by using the following formula:

$$\lambda_i(\text{control}) = \lambda_i(\text{lab}) \pm [0.5 + 10R_i] \text{ Å}, \qquad (1)$$

where R_i is a uniformly distributed random number between zero and one. The $\frac{1}{2}$ Å has been added to the bracket so that the laboratory and control wavelengths could never coincide. Half of the control sets were generated with the positive sign and half with the negative. One then searches for the lines on each of these control sets with the same tolerance, w. From the number found on the various control sets one can determine the mean number of chance coincidences, $\langle H \rangle$, and the standard deviation, σ , of the distribution about the mean. One then simply calculates what we have called the significance, S. If H_0 is the number of coincidences on the laboratory wavelengths, then

$$S = \frac{H_0 - \langle H \rangle}{\sigma} \,. \tag{2}$$

This may be directly interpreted in terms of a probability of chance occurrence on the assumption that the distribution of the number of coincidences on the various control sets is Gaussian. A sample distribution is shown in figure 1 for Pm II in HR 465 with 1000 control sets. In most of the cases we have examined in which more than a few lines have been used this assumption is justified. However, the fraction f of the control sets on which there were as many or more coincidences than on the laboratory wavelengths is an estimate of the probability of chance occurrence independent of any assumptions about the distribution.

The selection of the most suitable laboratory line list and tolerance is difficult. We have generally chosen the strongest lines in the laboratory spectrum, depending on our subjective judgment of the richness of the laboratory spectrum. The tolerance adopted must depend on the uncertainty in both the laboratory and stellar wavelengths. The



FIG. 1.—The distribution of coincidences on 1000 control sets for Pm II in HR 465. H is the number of coincidences, and N(H) is the number of control sets with H coincidences. The arrow indicates the number of coincidences on the laboratory wavelengths.

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uncertainty in the stellar wavelengths is usually of the order of ± 0.01 Å, and many laboratory wavelengths are of comparable or better accuracy. Some laboratory work is much less reliable. Furthermore, hyperfine splitting and isotope shifts can cause systematic differences between laboratory and stellar wavelengths. In light of these considerations and the fact that the wavelength of weaker lines can be influenced by blending, we have adopted a tolerance of ± 0.06 Å. Most of the well-identified elements would probably have larger values of S if a smaller tolerance were used, but these elements are easily identified anyway and need no additional support. In marginal cases we usually perform the significance tests for a variety of tolerance windows to ensure that the results are not due to a bizarre line distribution. It should be noted that a line coincidence rate which is not significantly above random does not necessarily imply that the element in question is not represented in the stellar spectrum. No claim is made that we always chose the best laboratory line list.

For each element we also examine a histogram of the wavelength residuals. Let us define $\Delta\lambda$ by

$$\Delta \lambda = \lambda_{\rm lab} - \lambda_{\rm star} \,, \tag{3}$$

where it is assumed that the stellar wavelengths have been corrected for the star's radial velocity. For a well-identified element ($S \ge 5$, or so), one would expect that a histogram of the $\Delta\lambda$'s would be sharply peaked at $\Delta\lambda = 0$. This is indeed the case, as most of the histograms in figure 2 illustrate. However, for trace elements we found that very little additional support for an identification can be found from such histograms.

The principal strength of this method is that it provides an impersonal, quantitative, figure of merit, S, for each identification. Like all statistical methods, it is most suitable for dealing with large numbers of lines. Some of the simpler spectra, Na I, Ca II, Sr II, Mg II, Si II, etc., may be positively identified on the basis of a *few strong lines*, and a statistical method is probably superfluous. As the characteristic lines weaken, the quantity f may be of interest, but the method probably does not add a great deal to the information available from standard methods for such cases. This statistical method is well suited to the examination of rare-earth spectra because of the large number of lines of similar intensity.

III. GENERAL SPECTROSCOPIC PROPERTIES OF HR 465 AND HR 7575

Preston and Wolff (1970) discussed the general spectroscopic and magnetic properties of the sharp-lined Cr-Eu Ap star HR 465 (HD 9996). They found that it is a magnetic and spectrum variable with a period of 22 to 24 years. The magnetic field varied between about ± 1 kilogauss. The lines of Eu II appeared to vary in phase with the magnetic field while Cr II was out of phase. The date of our observations (1960–1961) corresponds to a maximum spectral richness as well as maximum magnetic intensity.

HR 7575 (HD 188041) is a somewhat cooler Ap star which also shows a high density of sharp lines. It was discussed by Babcock (1954) as a magnetic and spectrum variable with a period of 226 days. (Also see Preston 1970.) The lines of Eu II and Gd II vary in phase with the magnetic field except the Gd II minimum was slightly advanced from the magnetic minimum.

IV. RESULTS FOR HR 465 AND HR 7575

The basic data for HR 465 is the line list prepared by W. P. Bidelman. This list is based on two Lick coudé spectrograms taken on 1960 September 6 and 1961 September 26. The 2 Å mm⁻¹ plates were measured by Diane M. Pyper. The wavelengths shorter than 3900 Å are from the 1961 plate. We have examined the wavelengths from the two plates to see if a systematic difference in the two plates could account for some



FIG. 2.—Delta lambda histograms for some well-identified elements in HR 465 and HR 7575. The significance, S, for each is indicated.

of our flat-topped $\Delta\lambda$ histograms. There is evidence for a small wavelength shift in the sense that the 1961 wavelengths are (shorter) by about 0.01 Å. This shift was deemed too small to merit further consideration.

The first entry in the wavelength list is at $\lambda 3180.73$, and the last is at $\lambda 4731.50$, but the plates were very faint at these wavelengths and it is not to be expected that the lines of trace elements would be visible throughout this region.

The HR 7575 data is based on a 2.3 Å mm⁻¹ plate taken by A. P. C. at the 84-inch (213-cm) coudé spectrograph at Kitt Peak on 1971 May 3. The plate was measured on the Grant engine, and the measurements were reduced to wavelengths at the offices of the National Observatory in Tucson with extensive help in the computer reduction from Mr. Wayne Warren. The measurements are within the region 3706.13 $< \lambda < 4678.84$. Some 2500 wavelengths are measured.

Table 1 gives the results of the significance tests for all elements which have been considered. All results in this table are for a tolerance of ± 0.06 Å and, except where

TABLE	1
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WAVELENGTH	COINCIDENCE	STATISTICS	FOR	HR	465	AND	HR	7575

		ER 465			HR 7575		
	H _o /N	8	f	h _o /n	8	f	References
Ne I Ne II Al II Si II P II	5/24 8/18 5/14 5/5 15/46	0.09 1.40 -0.24 2.57 0.10	0.47 0.09 0.69 0.02 0.53	5/14 6/15 2/8 5/5 10/29	0.71 0.86 -0.31 3.23 0.66	0.31 0.31 0.71 <0.01 0.25	20 20 20 13 20
S I S II Cl II Ar I Ar II	2/3 11/28 12/40 12/38 17/35	3.38 0.50 -0.41 -0.20 1.74	0.02 0.35 0.72 0.68 0.05	6/23 14/33 11/26 10/24	-0.81 1.29 1.06 1.31	0.86 0.12 0.21 0.15	20 20 20 20 20
Sc II Ti II V II Cr II Mn II	30/62 96/133 97/184 89/120 57/102	2.15 8.86 3.41 8.32 4.20	0.01 <0.01 <0.01 <0.01 <0.01	13/19 72/86 42/103 51/58 36/51	3.18 11.31 2.14 9.00 6.68	<0.01 <0.01 0.01 <0.01 <0.01	19 19 19 19 19
Fe I Fe II Co I Co II Ni I	54/59 66/81 24/42 14/15 5/21	8.03 9.02 1.93 3.81 -1.63	<0.01 <0.01 0.03 <0.01 0.96	29/42 47/53 5/7 1/1	5.17 9.28 2.10 1.36	<0.01* <0.01 0.047	10 19 10 19 19 10
Ni II Cu II Zn I Zn II Ga II	9/22 3/7 4/8 4/12 8/17	0.07 1.46 1.12 -0.54 0.78	0.53 0.18 0.26 0.80 0.27	5/10 2/3 2/7 4/9 1/6	1.43 1.59 -0.05 0.75 -0.81	0.17 0.20 0.66 0.33 0.90	19 13 20 20 15
Ge I Ge II As II Se II Br I	1/2 1/4 10/28 10/26 1/12	1.07 0.28 0.92 0.60 -1.43	0.38 0.64 0.26 0.40 0.99	0/1 9/26 13/26 7/12	-0.70 0.45 2.13 1.79	1.00 0.38 0.03 0.07	20 20 20 20 20 20
Br II Kr I Kr II Y II Zr II	1/7 1/12 21/54 21/40 69/72	-0.94 -1.60 1.08 1.98 8.64	0.90 0.99 0.17 0.04 <0.01	1/5 3/12 8/46 9/24 9/20	-0.69 -0.43 -1.66 0.60 1.38	0.87 0.76 0.94 0.36 0.13	20 20 20 10,13 10
Nb II Mo I Mo II Ru I Ru II	24/26 7/19 19/26 18/42 2/3	5.71 -0.19 3.64 0.68 1.12	<0.01 0.68 <0.01 0.32 0.33	4/11 4/14 5/12 10/31	0.20 -0.34 1.09 0.63	0.55 0.70 0.24 0.33	13 20 13 20 20
Rh I Pd I Pd II Ag I Ag II	15/39 14/19 0/2 2/7 3/5	-0.31 3.21 -1.05 -0.61 1.35	0.71 <0.01 1.00 0.86 0.19	3/16 2/6 3/5 1/3	-1.25 0.26 1.60 -0.22	0.96 0.58 0.14 0.81	20 20 20 20 20 20
Cd II In I In II Sn I Sn II	1/5 1/2 5/12 2/4 0/3	-0.85 0.85 1.51 0.68 -1.38	0.93 0.40 0.17 0.43 1.00	1/3 1/2 2/6 0/2	0.15 0.46 0.45 -0.96	0.69 0.59 0.44 1.00	20 20 20 20 20
Sb II Te II Xe I Xe II Cs II	7/23 18/31 2/13 7/23 12/38	0.62 2.65 -0.88 0.13 0.05	0.36 0.007† 0.93 0.55 0.53	7/21 8/19 3/10 6/21 18/35	0.25 0.99 -0.13 -0.03 2.65	0.48 0.19 0.71 0.62 0.0051	20 5 20 20 20 20
La II Ce II Pr II Pr III Nd II	25/61 66/103 18/35 21/49 56/57	0.88 5.22 1.81 0.98 8.83	0.22 <0.01 0.04 0.18 <0.01	32/52 66/88 14/35 6/23 25/56	5.03 7.77 0.68 -0.49 1.84	<0.01 <0.01 0.31 0.74 0.04	10 10 10 17 10
Pm II Sm II Eu II Gd II Tb II	76/166 100/110 10/11 78/81 54/80	2.08 11.80 3.93 10.69 4.60	0.022 [†] <0.01 <0.01 <0.01 <0.01	13/36 36/92 8/9 33/42 8/29	0.60 2.09 4.05 7.33 -0.72	0.36 0.05 <0.01 <0.01 0.86	12,14 10 10 10 10

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TABLE 1 - continued

		HR 465			HR 7575		
	H₀/N	S	f	H _o /N	S	ŕ	References
Dy II	90/94	10.23	<0.01	13/37	0.26	0.46	10
Ho II	34/50	3.46	<0.01	6/17	0.16	0.48	10
Er II	42/53	6.84	<0.01	6/17	0.40	0.42	10
Tm II	18/43	0.68	0.30	3/12	-0.29	0.72	10
YP II	47/99	1.87	0.04	15/48	-0.01	0.54	9
Yb III	13/36	0.04	0.56	10/25	1.16	0.15	1
Lu I	22/58	0.75	0.29	16/41	1.04	0.19	10
Lu II	6/24	-1.60	0,98	3/14	-0.87	0.89	11
Hf II	33/53	4.12	<0.01	8/28	-0.24	0.66	10
Ta II	34/69	1.68	0.07	3/18	-1.33	0.92	6
Os I	4/11	0.05	0.59	3/8	0.19	0.62	20
Os II	10/12	3.16	<0.01	4/7	1.25	0.19	20
Ir I	1/3	-0.54	0.91	0/1	-0.62	1.00	20
Ir II	0/1	-0.75	1.00	•			20
Pt II	8/26	-1.05	0.89	4/15	-0.41	0.74	16
Au II	4/10	-0.36	0.76	2/7	-0.27	0.71	2
Tl I	1/3	-0.21	0.76	0/1	-0.70	1.00	20
Tl II	5/7	1.70	0.11	3/6	0.97	0.33	20
Pb I	3/10	-0.41	0.72	1/6	-0.59	0.84	20
Pb II	1/8	-0.95	0.94	2/8	-0.15	0 .6 9	20
BII	2/5	0.06	0.64	1/3	0.21	0.65	20
Ac II	14/32	1.10	0.21	6/15	0.79	0.24	8
Th II	21/41	1.60	0.08	8/20	0.51	0.42	10
Pa II	9/22	0.31	0.53	3/11	-0.52	0.81	20
U II	23/32	3.80	0.0001	11/28	0.88	0.26	10
Pu II	34/93	0.87	0.23	27/91	-0.29	0.65	7
Am II	18/40	1.00	0.20	4/18	-0.78	0.85	ıģ
Cm	45/128	-0.76	0.83	40/111	0.70	0.26	20
Bk	10/20	0.79	0.29	1/9	-0.88	0.91	4
Cf	5/14	-0.30	0.70	3/14	-0.40	0.74	20
Es	4/9	0.27	0.51	3/4	2.16	0.0541	⁺ 3

Some of the Fe I lines used in the reduction of the measurements were not on the wavelength list

Based on 1000 control sets Based on 10,000 control sets

References

1234567890	Bryant (1961)	11	Meggers and Scribner (1937)
	Ehrhardt and Davis (1971)	12	Meggers, et al. (1951)
	Gutmacher, et al. (1967)	13	Moore (1959)
	Gutmacher, et al. (1965)	14	Reader and Davis (1972)
	Handrup and Mack (1964)	15	Sawyer and Lang (1929)
	Kiess (1962)	16	Shenstone (1938)
	Korostyleva (1964)	17	Sugar (1961)
	Meggers (1957)	18	Thorne (1956)
	Meggers (1957)	19	Warner (1967)
	Meggers, et al. (1961)	20	Zaidel', et al. (1970)

indicated, were obtained using 100 control sets. The column labeled H/N gives the number of lines found over the number of lines in the laboratory line list. The quantities S and f were defined in § II. It should be pointed out that some elements have been retained in this table for completeness even though the number of lines that were searched for was too small to produce a statistically significant result even if all the lines were found.

Figures 3 and 4 show histograms of S for HR 465 and HR 7575, respectively. If the assumption of Gaussian statistics were always correct and if none of the spectra looked for were present in the star, then one would expect this distribution to approximate a

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FIG. 3.—Histogram of the S's given in table 1 for HR 465. The shaded section includes only those elements for which more than 10 lines were used.

Gaussian. Neither of these assumptions is correct; but if they were, one would expect about two (chance) values of S larger than +2.0 in each star. Because a substantial number of the elements are clearly present in the spectra of these stars, there should be less than two chance results with S greater than 2.0. (We call attention to one such result: Es II in HR 7575!)

Table 2 gives the identifications that we have made based on all considerations (not just the line coincidence tests). Bidelman (unpublished) had previously made most of these identifications in HR 465. We have divided these into three groups. We feel that the identifications in the first group, labeled "definite," are absolutely certain. Those in the second group, labeled "good," we firmly believe, but the evidence for their identification is not as overwhelming. The elements in the group labeled "possible" are somewhat uncertain. We cannot deny the possibility that one or even two of these identifications are wrong. It is extremely unlikely that all or even most of them are wrong. Some of these elements will be discussed in detail below.



FIG. 4.—Histogram of the S's given in table 1 for HR 7575. The shaded section includes only those elements for which more than 10 lines were used.

TABLE 2

	Element	IDENTIFICATIONS	IN	HR 4	165	AND	HR	7575	
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Star	Definite	Good	Possible
HR 465	Si II, Ca II, Ti II, Cr II Fe I, Fe II, Sr II, Zr II, Nb II, Ce II, Nd II, Sm II, Fu II, Cd II, Dy II, Fr II,	Mg II, Sc II, V II, Mn II, Co II, Mo II, Pd I, Tb II, Ho II, Hf II, Pt II, Hg II, U и	Ү п, Те п, Рт п, Үb п, Оs п
HR 7575	Mg II, Ca II, Ti II, Cr II, Mn II, Fe I, Fe II, Sr II, La II, Ce II, Eu II, Gd II	Si II, Sc II	Co 1, Se 11, Cs 11, Nd 11, Sm 11

a) HR 465

i) Pm II

The promethium identification has been extensively discussed elsewhere in the literature (Havnes and van den Heuvel 1972; Aller and Cowley 1972; Wolff and Morrison 1972; Cowley and Aller 1972). For a full discussion the reader is referred to those papers.

In addition to the coincidence test listed in table 1, several other tolerances have been tried, and the results are given in table 3. The results in this table run about as expected, with the glaring exception of ± 0.07 Å. We have also tried using only the 45 strongest lines on our list and have found no significance at any tolerance. This last result is similar to that arrived at by Wolff and Morrison (1972). The higher significance which occurs when the larger set of lines is used, is due to a higher coincidence rate with lines of intensity 10 to 30 on the scale of Meggers, Scribner, and Bozman (1951). The 45 lines of intensity 30 to 100 show essentially a random coincidence rate.

The interpretation of these results is very difficult. The Meggers *et al.* intensities are eye estimates from photographic plates using a source with a much lower excitation temperature than that of HR 465. This makes it unclear what meaning can be attached to these intensities. Furthermore, almost all of the 45 strongest lines can be found on tracings of the plate. For these reasons it is not possible to draw a definite conclusion one way or the other at the present time. We, however, remain optimistic and hope that further laboratory work, which is currently in progress, will help clarify this situation.

іі) Теп

We originally obtained a significance S of about 2.0 using a list of 13 of the strongest lines. We then enlarged the list to 31 lines and obtained the result shown in table 1. The wavelength agreement is not outstanding. However, the laboratory wavelengths

COINCIDENCE TESTS FOR Pm II								
W (Å)	H/N	S	f	Number of Control Sets				
0.06	76/166	2.080	0.022	1000				
0.07	82/166	1.300	0.105	200				
0.08	97/166	2.118	0.015	200				
0.09	103/166	1.874	0.025	200				
0.10	109/166	1.793	0.050	200				
0.11	114/166	1.528	0.07	100				

TABLE 3

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are from a compilation by Handrup and Mack (1964), and this work shows differences of up to 0.06 Å between different sets of wavelength measurements. We have tried other tolerances and have obtained similar significances except at small tolerances (i.e., \leq 0.04 Å). We have also made a line-by-line search of the tracings which generally supports the identification. About five lines cannot be identified with a feature which is above the noise level on the tracing. Most of those cases, however, are at the extreme red end where the plate is quite weak, and one cannot expect to find weak lines.

iii) Pt п

Bidelman (unpublished) first proposed this identification (see Aller 1972). The results of the coincidence tests given in table 1, however, certainly do not provide any support for this identification. We were persuaded that Pt II is present in HR 465 when the stronger lines of Pt II were compared with the corresponding features on a tracing of a 2.3 Å mm⁻¹ plate we have of HR 4072. Pt II was identified in HR 4072 by Dworetsky (1969), and we have found a high confidence level (S = 5.8) for the identification. Table 4 gives a comparison of the equivalent widths of all Pt II lines in HR 4072 given by Dworetsky (1969) with the eye estimates of the intensities of the features in HR 465. The line λ 4288 is clearly present on the tracing and apparently was accidentally omitted from the line list. The intensity given for λ 4514 is probably not on a consistent scale with the other lines. A more appropriate value for this line might be 4. The comparison in table 4 is not as convincing as the examination of the tracings, but we feel that it indicates the presence of Pt II in HR 465. It should be pointed out that some of the rather large wavelength discrepancies between HR 465 and HR 4072 may be due to different isotopic abundances. Dworetsky (1969) indicated that isotope shifts may exist in Pt II.

iv) Uп

The uranium identification has been previously reported (Hartoog and Cowley 1972; Cowley and Hartoog 1972). We have made a line-by-line examination of the tracings of HR 465 for most of the uranium lines and this supports the identification. All 12 of the strongest lines are present on the line list except one which is blended with H ζ . Some of these lines are in blends where they are obviously not the principal contributor, and the general wavelength agreement reflects this. However, the strongest line of U II (λ 3860) is clearly present, apparently not seriously blended, and no

$\lambda_{ ext{lab}}$ (Å)	λ _{HR 4072} (Å) (Dworetsky 1969)	W_{λ} (mÅ) HR 4072 (Dworetsky 1969)	$\lambda_{ m HR~465}$ (Å)	<i>I</i> (Bidelman)		
	3447.80	13	3447.78	3		
3577.20	3577.23	8				
3766.40	3766.46	8				
3806.91	3807.00	19	3806.88	2		
4023.81	4023.85	16	4023.85	2		
4034.17	4034.20	19	4034.25	2 blended		
4046.45	4046.51	54	4046.39	3 seriously blended		
4061.66	4061.68	41	4061.68	4		
4148.30	4148.33	10	4148.22	1		
4288.40	4288.45	19		clearly on tracing		
4514.17	4514.20	47	4514.12	6		

TABLE 4

Pt II	WAVELENGTH	AND IN	TENSITY (COMPARISON	FOR	HR	465	AND	HR	4072

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other acceptable identification can be found for it. Also the line λ 4242, which is fairly free from serious blending, although weaker, is clearly present on the tracings. We feel that the identification of uranium is quite good.

v) Os II

Bidelman (unpublished) first proposed this identification. About half of the Os II lines are in blends where they are not the major contributor. The strongest line for which no other acceptable identification can be found is λ 3604. Also, the somewhat weaker line λ 3895 has no other acceptable identification. The wavelength agreement for these two lines is good, but the overall agreement is only fair for this element. The basic uncertainty in the identification is due to the small number of lines on which it is based. (Note: The reference in table 1 for Os II contains only some of the lines used. The reference to a more complete list is van Kleef 1960.)

b) HR 7575

i) Se II

Bidelman (1966) previously proposed the identification of Se II in HR 7575. Our results generally confirm those of Bidelman. Bidelman indicates the strongest lines of Se II are in the region of 5200 Å which is not covered by our plate of HR 7575. Thus, this identification is probably better than is indicated by the value of S.

ii) Cs II

We have made a line-by-line search of the tracings for most of the cesium lines used in the test given in table 1. This search indicated that many of the cesium lines, if they are present, are in general quite weak. The lines in question all arise from excitation potentials around 15 eV or higher. Thus even marginal visibility of these lines would indicate a substantial overabundance. We propose this only as a possible identification and indicate that further work is needed.

V. DISCUSSION

While HR 465 and HR 7575 may superficially resemble one another at low dispersion, it is clear at high dispersion that the stars are dissimilar in many respects. A sideby-side comparison of the high-dispersion plates reveals that HR 465 had a much richer spectrum in 1960–1961, especially in weak lines.

An examination of table 2 confirms these subjective impressions. Both stars show the spectra of the iron-peak elements quite prominently. However, only HR 7575 shows evidence for selenium. Zirconium, niobium, and to a lesser extent molybdenum are prominent in HR 465 but completely absent or very weak in HR 7575. In the rareearth group there also are substantial differences. The most abundant rare earths in HR 465 are neodymium and samarium (Aller 1972). These elements are only marginally present in HR 7575. The prominent rare earths in HR 7575 are cerium, europium, and gadolinium. All of these elements are also present in HR 465; but lanthanum, which is only slightly less prominent in HR 7575 than the rare earths, is absent or very weak in HR 465. HR 465 also shows some of the heavier rare earths, namely, terbium, dysprosium, holmium, and erbium; HR 7575 does not. Finally HR 7575 shows no evidence of elements heavier than the rare earths, while HR 465 shows platinum, mercury, uranium, and probably osmium.

The question naturally arises whether these differences are real abundance differences or whether they are simply due to different temperatures of the stars. Cerium and neodymium, which have almost identical ionization potentials and lines arising from similar excitation potentials, behave differently in the two stars, which argues

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against the temperature difference being responsible. For platinum and mercury it is possible that the lower temperature of HR 7575 makes the identification of these elements more difficult.

It would appear that HR 7575 is a fairly typical Cr-Eu star. HR 465 on the other hand, has some of the properties usually associated with both the Hg-Mn and the Cr-Eu stars. Manganese is the most overabundant of the iron-peak elements (Aller 1972), although it is not easily seen because of the overwhelming strength of some of the other lines. The presence of mercury and platinum is also usually associated with the Hg-Mn stars, while the rare earths, the large magnetic field, and the spectrum variations are usually associated with the Cr-Eu stars. This suggests that HR 465 is perhaps some sort of an intermediate object lying between the Hg-Mn and Cr-Eu stars. This raises the possibility that there may be some relation between these two types of peculiar stars.

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