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ABSTRACT

Well-widened, high-dispersion spectra were used to obtain the identifications and equivalent widths for over 1500 lines between 3700 Å and 4900 Å for the relatively cool Ap star, HD 204411. A model atmosphere analysis of these data was performed. The large number of lines used in this study allowed us to discuss and rule out any significant departures from LTE in the level populations for the lines, or any large variation of the turbulent velocity parameter with height. The results suggest a broadening of the Fe peak abundances, an overall enhancement of the Fe peak relative to H, and a decrease in the ratio of light element abundances to iron. The evidence also indicates that the s-process elements Sr and Zr have normal abundances relative to Fe.

I. INTRODUCTION

HD 204411 (HR 8612, BD + 48° 3990) was classified by Morgan (1932) as a peculiar star (HD type A3) of the Eu-Cr class. Colors for this star were observed by Provin (1953), who obtained (U-B) = +0.17, (B-V) = 0.06. Provin

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suggested that HD 204411 exhibited some indications of light variability, though probably not exceeding ±0.02 mag in U, B, or V. Later observations by Rakos (1963) indicate that the brightness changes, if any, are very small ($\leq$0.01 mag) and largest in the ultraviolet. No indication of a definite period was found. In the Wilson (1953) catalog of radial velocities a total range of 3 km/sec is reported for ten plates taken at Lick, Yerkes, and Victoria. We conclude that there is no compelling evidence for radial velocity variations. Babcock (1958) lists this star among those having probable, though not firmly established, magnetic fields. We can therefore conclude that it is unlikely that this sharp-line star has a field much in excess of a few hundred gauss.

The above observational evidence suggests that HD 204411 is a favorable Ap star for study, for the following reasons.

1. It is representative of the class of fairly low-T_{eff} Ap stars, none of which has been the object of a detailed, model atmosphere analysis.

2. There are no large scale spectroscopic or light variations that would make the application of the model atmosphere technique seem questionable.

3. The influence of magnetic fields on line formation and the structure of the atmosphere is likely small, if not negligible.

4. The rotational velocity as estimated from our plate material is certainly less than 5 km/sec.

Therefore, HD 204411 is an extremely sharp-line object, ideal for an extensive line identification, equivalent width, and model atmosphere study.

II. THE OBSERVATIONAL DATA

We obtained two spectra in the wavelength region 3700 Å to 4900 Å using a baked IIa-0 emulsion and the 72-inch camera combined with the 133B grating of the 100-inch reflector at Mt. Wilson. The spectra, of 4.5 Å/mm dispersion, were widened to 1 mm. A list of the lines identified as having equivalent widths, W_λ, greater than 5 mÅ is presented in Table 1. In column 1 we list the wavelength as measured from the plate; in column 2, the equivalent width;

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in column 3, the proposed identification; and in column 4, the corresponding laboratory wavelength. The equivalent widths were obtained from planimeter measurements of direct intensity tracings. We estimate from comparison of the two plates that the errors in W_λ are approximately ±10 per cent.

III. THE CHOICE OF T_{eff} AND log g

The relation between (B-V) and T_{eff} given by Kuhi, Woolf, and Hayes (1968) was used to deduce a minimum value of T_{eff} = 8500°K. Either enhanced differential line blocking between the B and V bands or interstellar reddening will act to increase the value of T_{eff}. We cannot rule out reddening, since the star is located at a galactic latitude b = -1°23' and the distance modulus is near 5 mag. We do not expect E_{B-V} to exceed about 0.07 mag, so that a maximum T_{eff} value would be approximately 9500°K. However, it is difficult to explain the (U-B) color by invoking reddening alone. It seems necessary to assume enhanced (relative to normal A stars) blocking in the U relative to the B band of approximately 0.10 to 0.12 mag. This seems entirely consistent with the enhanced abundance of the iron group elements relative to hydrogen and the average value of the turbulent parameter of 3.5 ± 0.5 km/sec we find in §IV.

A surface gravity of log g = 3.7 ± 0.4 was estimated from the Hγ profile observed by Searle and Sargent (1964), and from the atmospheres and hydrogen-line profiles described in Strom and Peterson (1968).

In accordance with the estimates of atmospheric parameters made above, we constructed a grid of model atmospheres in the range 8500° < T_{eff} < 9500°K with log g = 3.7 to 4.3. The program ATLAS, written by R. Kurucz and based on the methods outlined by Strom and Avrett (1965), was used to compute these models. Copies of ATLAS and a description of its operation are available from the authors upon request.

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The equivalent widths given in·Table· 1 were used to deduce abundances for each line of Fe I and Ti II for which the transition probabilities advocated by Warner (1968) were available. The models were used in conjunction with the atomic parameters for the lines to compute first the run of line opacity and source function with optical depth and then the emergent profiles and equivalent widths. The abundance was varied until the observed and computed equivalent widths were matched. For each model a range of turbulent velocity values, v_t, was used.

In Figures 1a, b, c we plot the deduced abundances, N, against the lower excitation potential of transition in question for the Fe I, Ti II, and Cr II lines, respectively. The value of T_{eff} = 8750°K used in these figures provides the minimum slope in the N vs χ plots. An error of 250°K is estimated for this determination of T_{eff}. A value of T_{eff} in the range 8500 < T_{eff} < 9000°K is consistent with the UBV colors.

We then chose the gravity by minimizing the differences in the mean values of the abundances deduced for Fe I and Fe II. We deduced a value of log g = 4. 3 ± 0. 3. This value is not badly inconsistent with that determined from the Hγ profile, although the probable error ranges in these two gravity determinations just barely overlap.

In order to determine the best value for v_t for the (8750, 4. 3, 1) model, we plotted the deduced abundances for Fe I, Ti II, and Cr II lines against the observed equivalent width for each line. We show these plots in Figures 2a, b, c for the chosen value of v_t = 3. 5 km/sec, which minimizes the slope of this relation for each of the elements. The error in the deduced value of v_t is about ±0. 5 km/sec.

In Figures 3a, b, c we plot, for the Fe I, Ti II, and Cr II lines, respectively, N against the mean depth of formation of each line, $\bar{\tau}$, which is chosen to be the continuum optical depth corresponding to a monochromatic depth τ_ν = 1 at a point on the line displaced one Doppler width from line center. We find no systematic trend of N with $\bar{\tau}$ to suggest that there are no crucial

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systematic errors in 1) the model structure, 2) the mechanism of line forma-
tion, or 3) the assumption that the turbulence parameter is independent of
depth.

We note from experience gained with numerical experiments that the
same conclusions are reached for more sophisticated definitions of $\bar{\tau}$ (e. g. ,
those based on contribution functions (Aller 1960)).

IV. THE RESULTS

To estimate the magnitude of the errors associated with our choice of
models, we have computed abundances for two models. The first is a
(8750, 4. 3, 1) model with v_t = 3. 5 km/sec, while the second is a (8500, 4, 1)
model with v_t = 4. 0 km/sec. We present in Table 2 for each of these models
the mean abundance values (based on the indicated number of lines) on a loga-
rithmic scale with H = 12. 00, and the probable errors of their mean values.
We also include a tabulation of the logarithmic element-to-iron ratios. The
final columns in Table 2 give the mean values of $[N/N_H]$ found by Conti and
Strom (1968a, b) from an analysis of nine normal early A stars, and the values
of the solar abundances found by Warner (1968). These values have a corres-
ponding probable error in the mean of the order of ±0. 1. We note that the
abundance values for the normal A stars coincide very closely with the solar
values. We find this agreement very encouraging, although we prefer to
remain somewhat cautious about assigning absolute values for the abundances
since the absolute values of the abundance ratios are, of course, sensitive to
the assumed transition probabilities. However, the comparison of the unknown
star (in this case HD 204411) relative to the average of the normal A stars is
independent of these values. This method, which uses the full power of the
model atmosphere approach, allows us the same advantages of a classical
differential curve-of-growth approach. We also believe that these results
are superior to the preliminary values given by Searle and Sargent (1964)
and Mihalas and Henshaw (1966) primarily owing to the careful way in which
the values of the model parameters were determined.

We find the following basic results:

1. The ratios of Mn, V, Cr, are enhanced relative to Fe by about 0.5 to 1.0 dex.

2. The ratios of Ca, Ni, Co, and Zr are enhanced relative to Fe by 0.2 to 0.5 dex.

3. The Fe/H ratio is most likely enhanced by about 0.4 to 0.6 dex.

4. The ratios of Mg and Si to H are normal to within their probable errors, although the ratios of these elements relative to Fe are down by 0.3 to 0.6 dex.

5. The ratios of Sc, Ti, Sr, and Y with respect to H are normal, and hence the ratios of the abundances of these elements relative to Fe are down by 0.3 to 0.5 dex.

We are somewhat puzzled by the lack of agreement between Ti I and Ti II. Warner obtains good ionization equilibrium for the sun using the identical scale of transition probabilities to that adopted here. We surmise that the Ti I abundance is most subject to error since these lines are weak and subject to blending.

6. La and Ce give abundances, comparable (to within 0.3 to 0.5 dex) with those deduced for Sirius from the values of W_λ given by Kohl (1964).

We therefore conclude that HD 204411 has very slight, if any, enhancement of rare earths.

7. We note that although $\lambda 4205$ of Eu II was thought to be seen by Morgan, our spectra show no lines within 0.040 Å of the laboratory position of this Eu II line. Moreover, we find no evidence for the Eu II line at $\lambda 4130$. Since both lines have values of gf within a factor of 1.5 of one another and we detect neither, it seems likely that the original identification of Morgan was, for some reason, erroneous.

Upper limits to the abundances for C I, Al I, Zn I, and Eu II were obtained by assuming 5 mÅ as an estimate of the minimal detectable equivalent width for our plate material.

For C I the 4771 line has been observed in a number of early A-star spectra (Conti and Strom 1968a, b). It appears that carbon is underabundant by at least a factor of 10 in HD 204411.

The Al I line at 3944 Å is also seen quite prominently in other A-star spectra, and we must conclude that Al is deficient in HD 204411 by a factor of at least 10.

The upper limit to the Eu abundance suggests a slight underabundance of this element.

The upper limit deduced for the Zn abundance is consistent with a normal abundance for that element.

V. INTERPRETATION

The results of the foregoing analysis of HD 204411 are, at first sight, surprising. Despite the fact that it is easily identifiable as a peculiar star at low dispersion and despite the large number of lines, particularly of Cr I and Cr II, in its spectrum, the composition of HD 204411 is not strikingly different from a normal star. On the other hand, the abundance abnormalities revealed by our analysis appear to offer more promise for an explanation in terms of nuclear physics than those of the other Ap stars studied to date. A comparison of the line list with that for normal A stars shows that, although the enhancement of Cr is most apparent at low dispersion, in fact there is an abnormal number of lines of Fe I and Fe II in the spectrum of HD 204411, as well as more lines of Cr I and Cr II. Thus the star's main peculiarity is an overall enhancement of the whole Fe peak relative to H. This is coupled with some change in the distribution of elements within the Fe peak and with a deficiency in carbon. The latter is the only element in the CNO group that

can be studied by the use of plates in the blue region of the spectrum. However, O I and N I could be studied in the photographic infrared region of the spectrum. By analogy with results obtained for other cool peculiar A stars (Sargent and Searle 1962), it is likely that O and N will prove to be deficient also.

In attempting to evolve a general theory to explain the abnormal compositions of the Ap stars, Fowler, Burbidge, Burbidge, and Hoyle (1965) have proposed that the deficiency in the light elements is caused by surface spallation reactions induced by changes in the internal structure of an evolved star. The excess of heavier elements is brought about by mixing to the surface of material that has been processed at high temperatures in the interior, or it is material that has originated in the interior of a binary companion. While there are objections to the application of this theory to the generality of Ap stars (Searle and Sargent 1967), it may apply to some Ap stars, including HD 204411.

Acknowledgments

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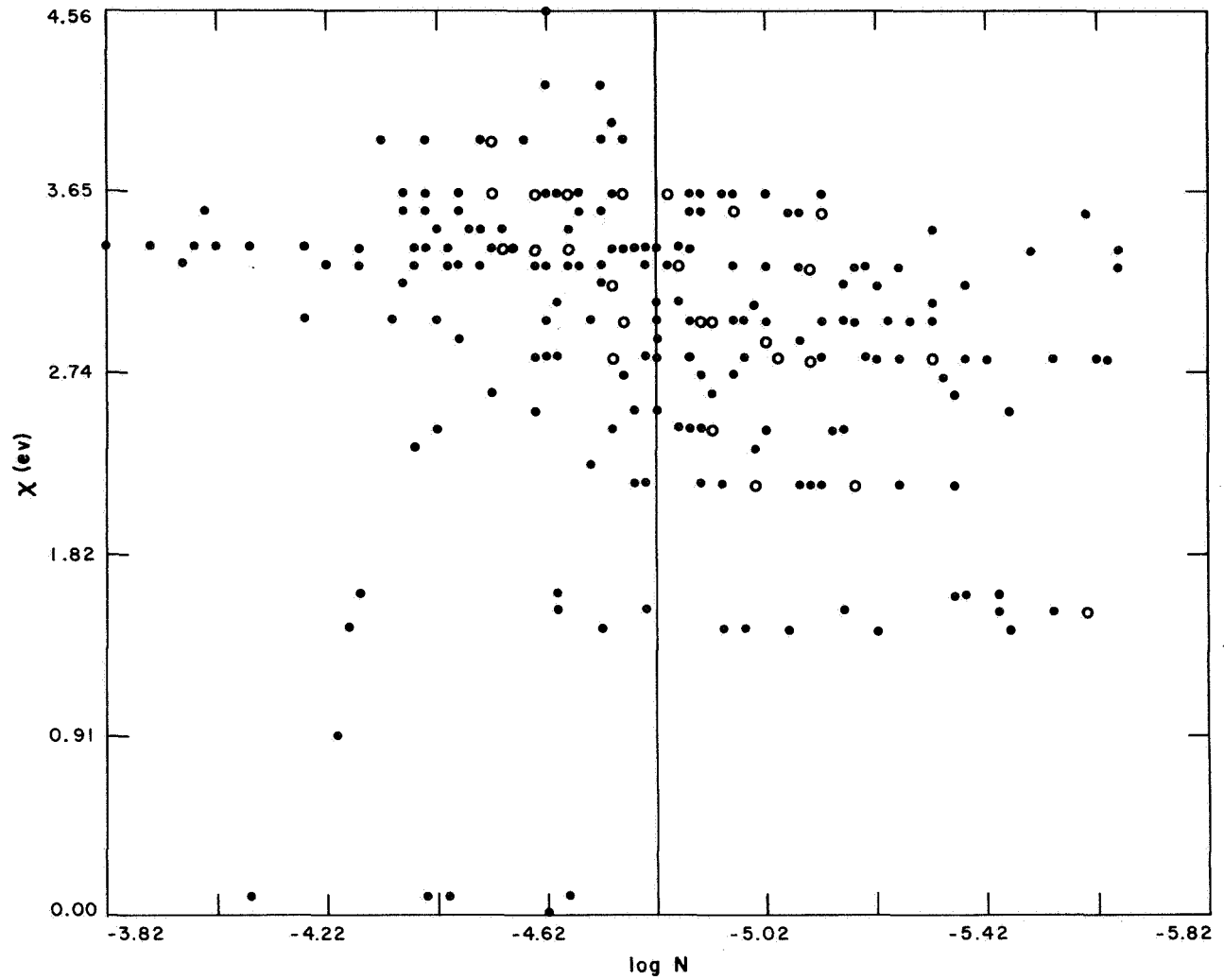
(a)

Figure 1.   Plot of deduced abundances for (a) Fe I, (b) Ti II, and (c) Cr II
lines against excitation potential for the model (8750, 4. 3, 1)
with v_t = 3. 5 km/sec.   Open circles represent two coincident
points.

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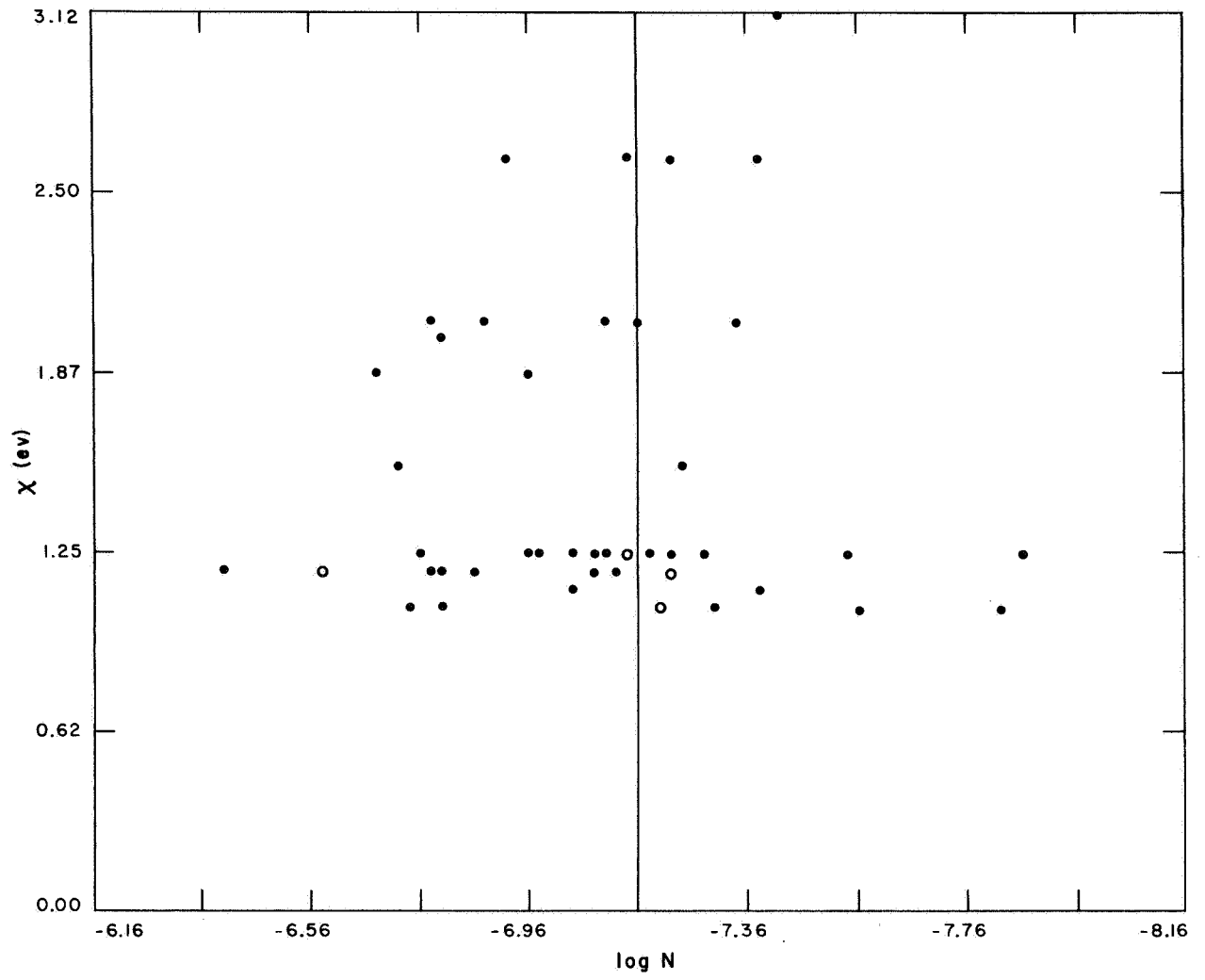
Figure 1. (b)

Figure 1. (c)

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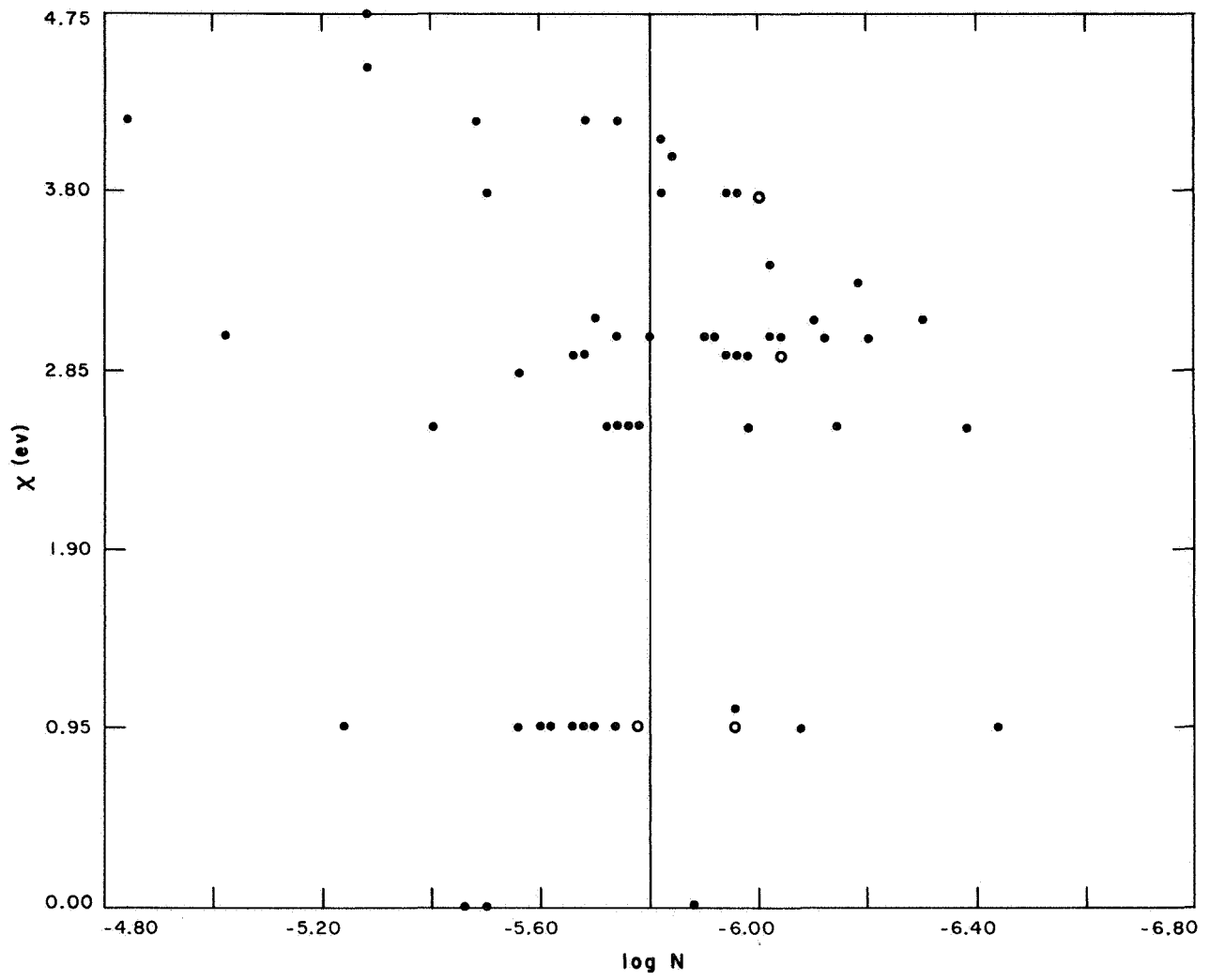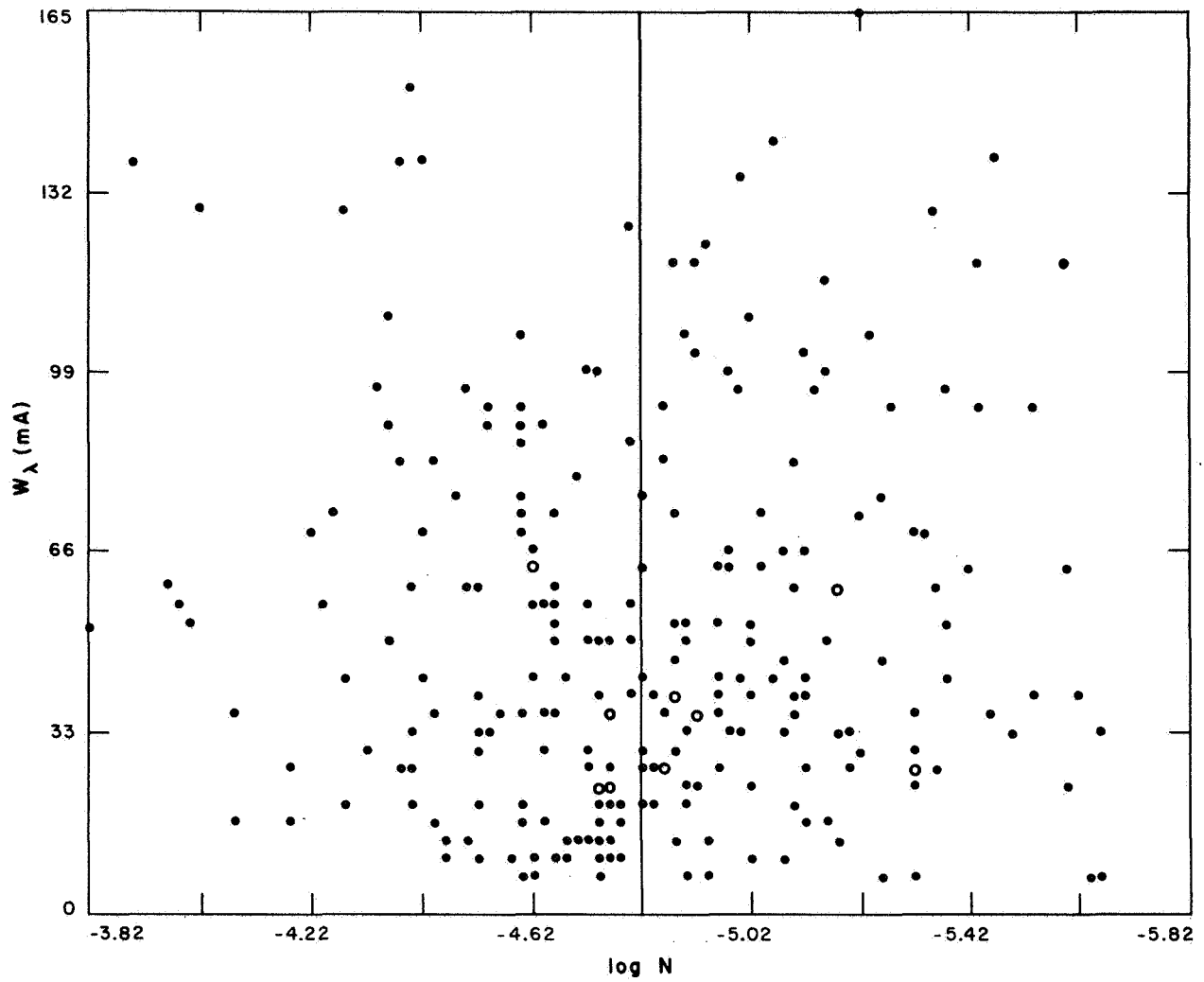
(a)

Figure 2. Plot of deduced abundances for (a) Fe I, (b) Ti II, and (c) Cr II
lines against equivalent width for the model (8750, 4. 3, 1) with
v_t = 3. 5 km/sec. Open circles represent two coincident points.

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Figure 2. (b)

Figure 2. (c)

(a)

Figure 3. Plot of deduced abundance for (a) Fe I, (b) Ti II, (c) Cr II against
mean depth of formation $\bar{\tau}$ (see text) for the model (8750, 4.3, 1)
with $v_t = 3.5$ km/sec. Open circles represent two coincident
points.

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Figure 3. (b)

Figure 3. (c)

TABLE 1

Lines Identified as Having Equivalent Widths, W_λ, Greater than 5 mÅ

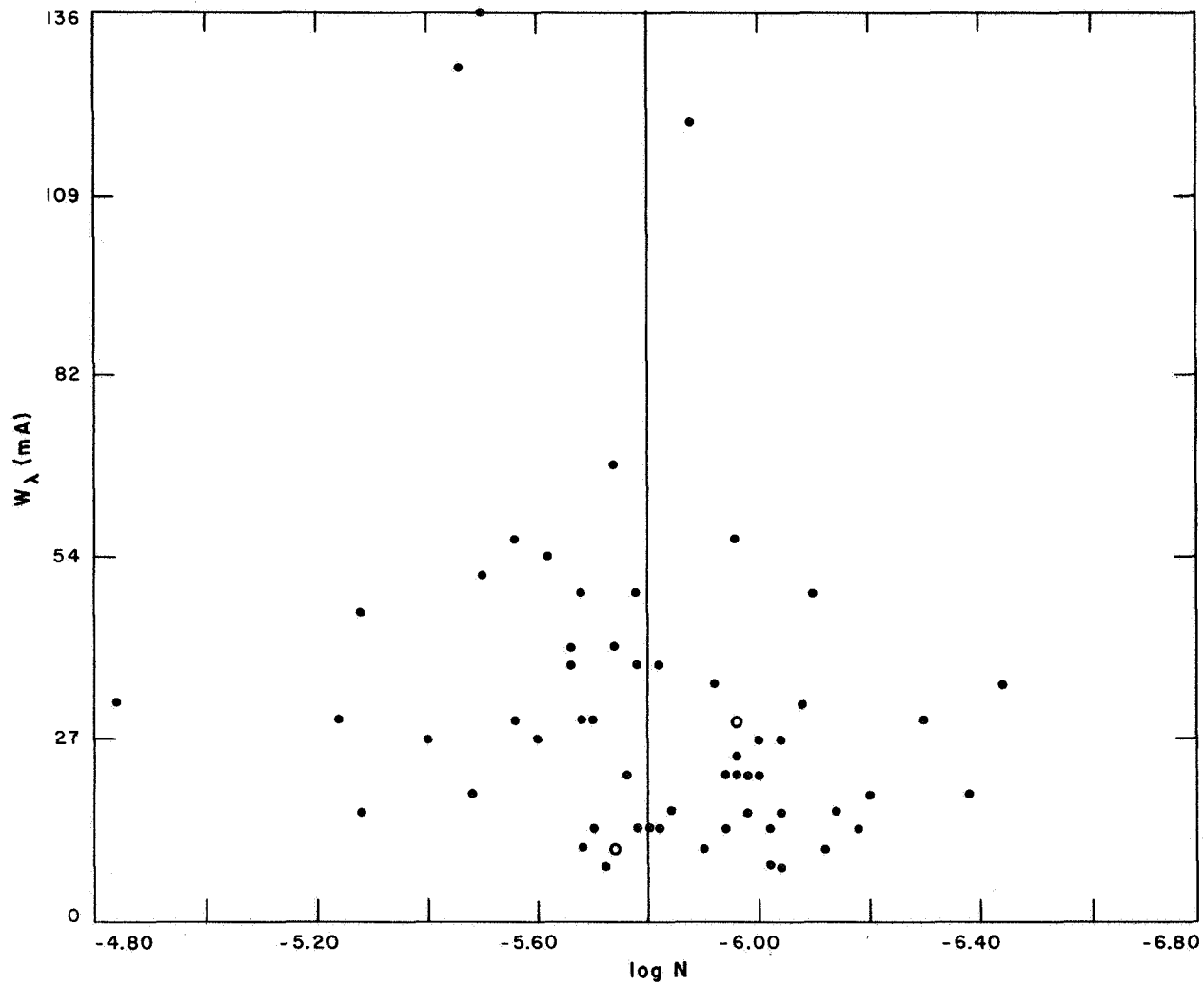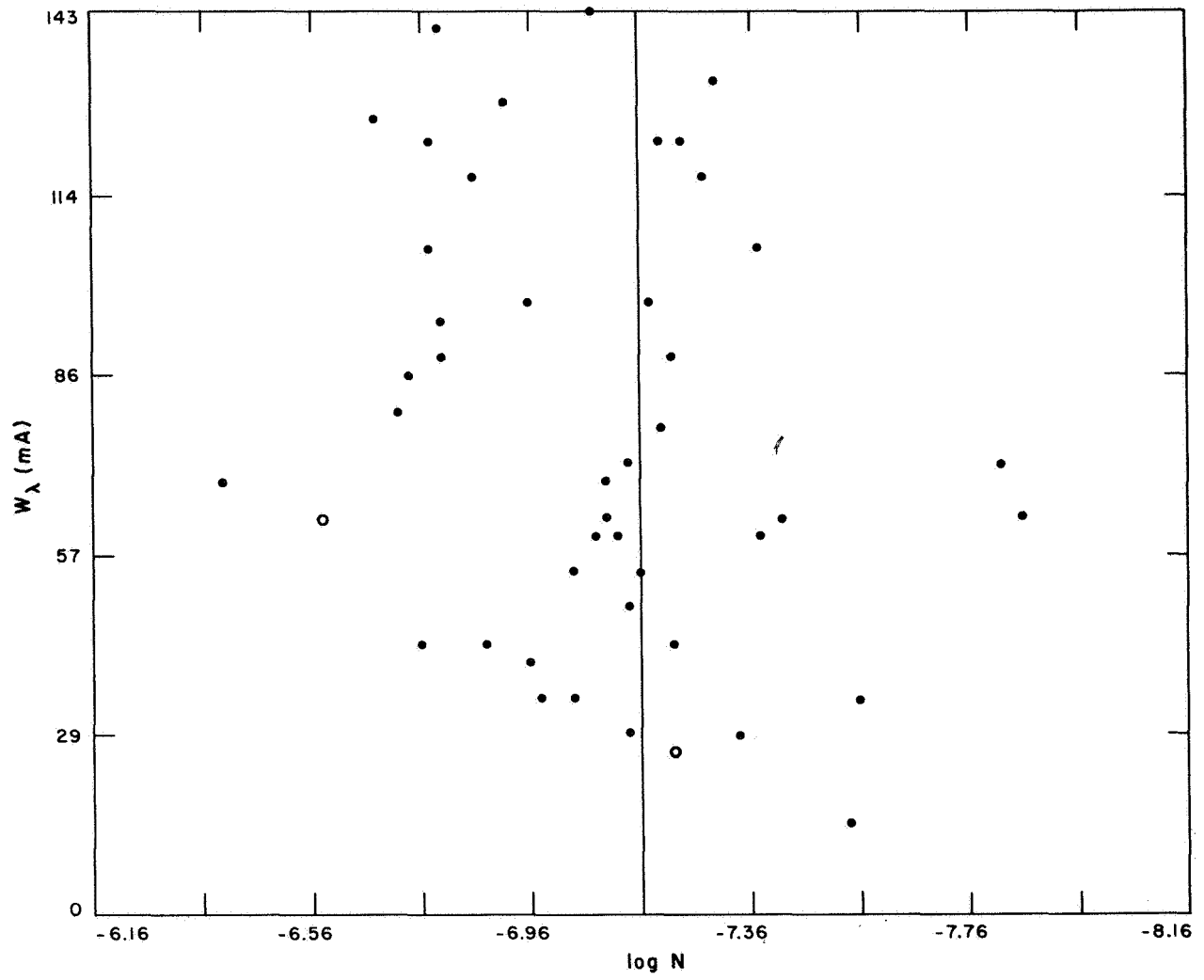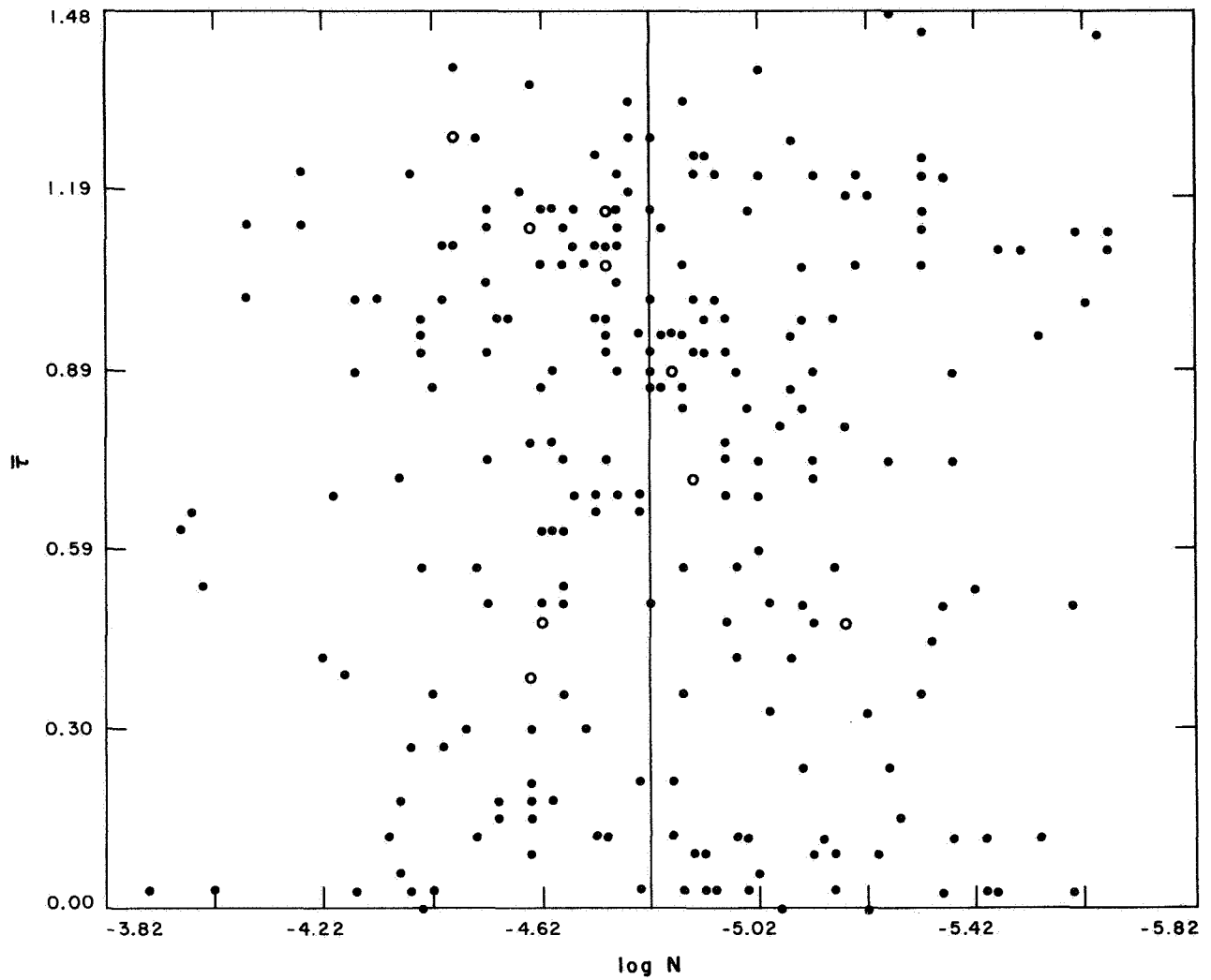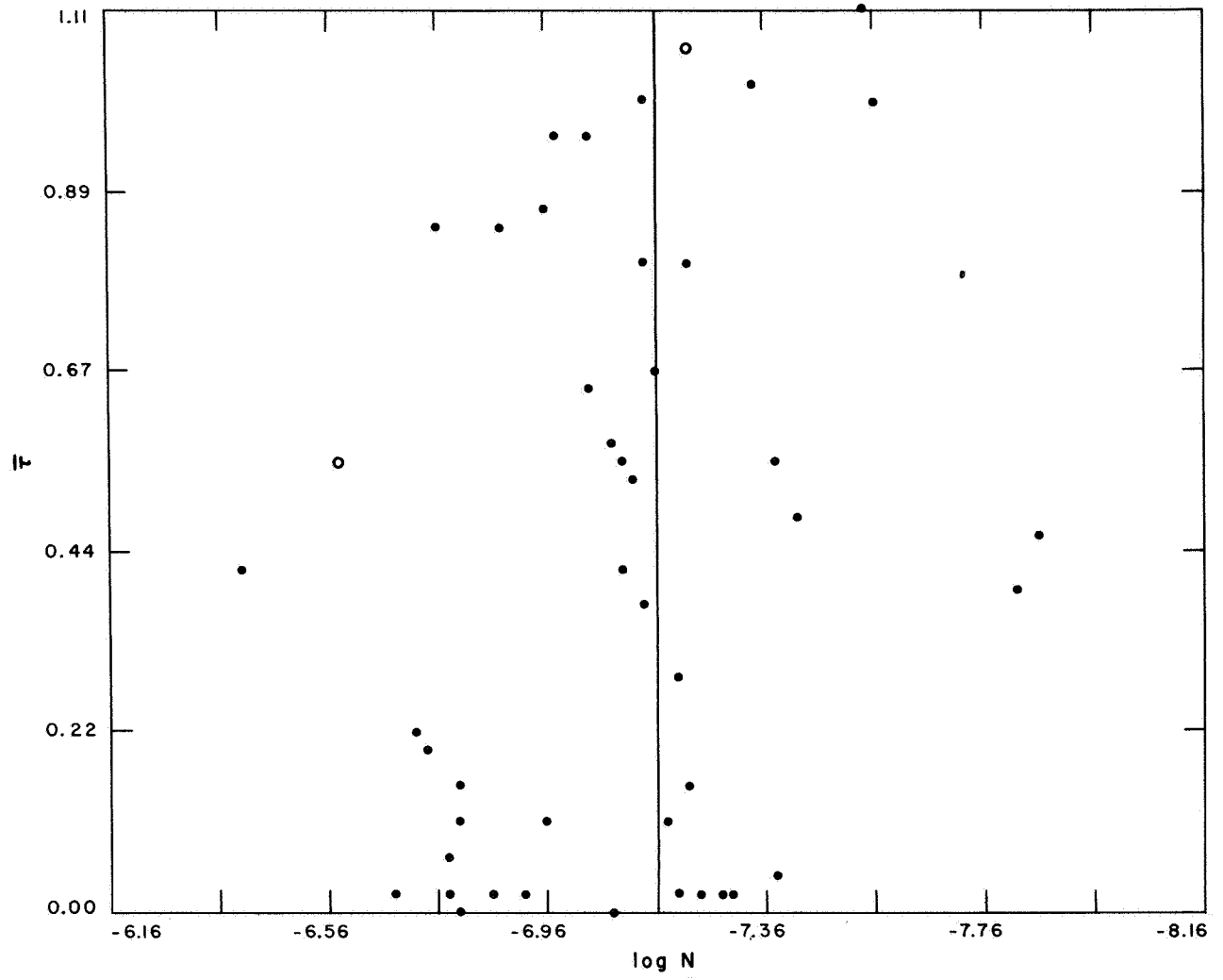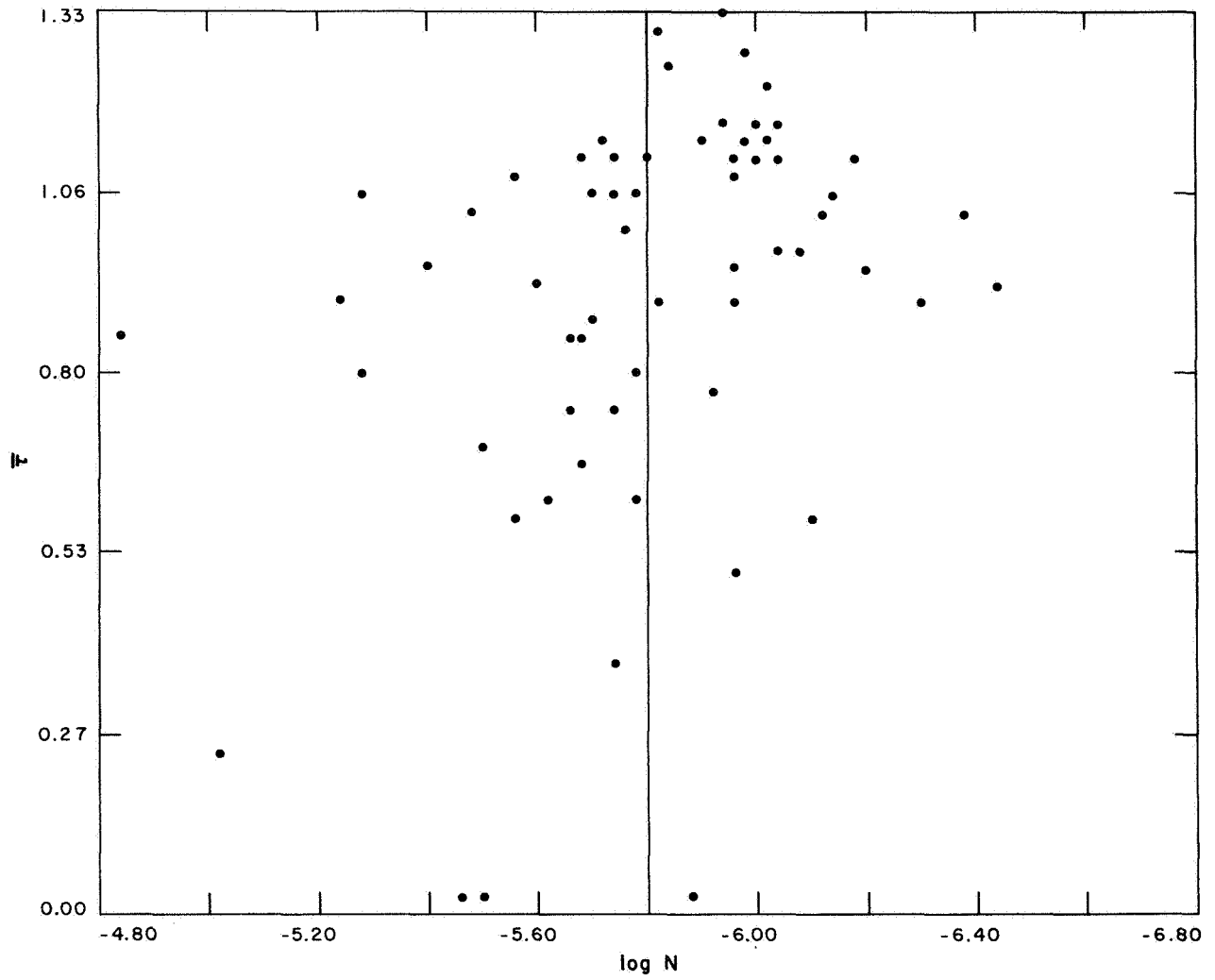| Measured wavelength	W_λ(mÅ)	Identification	Laboratory wavelength
3753.606	56	FeI(73)	0.610
54.593	76	CrII(20)	0,59
55.176	39	CrII(20)	0.13
55.685	26	CrII(8)	0.61
56.096	8	FeI(74)	0.069
56.349	37		
56.982	45	FeI(805)	0.939
57.442	26	FeI(668)?	
57.691	98	TiII(72)	0.684
58.247	101	(FeI(21))	0.235
		(CrII(8))	0.36
59.127	192	TiII(13)	0.291
60.058	31	FeI(177)	0.052
60.458	26	FeI(76)	0.534
60.714	1		
61.322	110	TiII(13)	0.320
61.685	52	CrII(11)	0.69
61.874	90	CrII(11)	0.90
62.274	6	FeI(705) ?	
62.999	29	FeII(192)	0.894
63.774	18	FeI(21)	0.790
64.111	45	FeI(21)	0.790
65.552	106	(FeI(608))	0.542
		(CrII(20))	0.62
66.681	34	CrII(20)	0.65
67.204	89	FeI(21)	0.194
68.090	49	(FeI(73))	0.030
		(CrI(42))	0.08
75.51	23	NiI(33)	
76.049	26	TiII(72)	0.062
76.389	10		
76.528	35	MnI(6)	0.527
78.339	32	VII(21)	0.357
78.742	41	FeI(73)	0.697
79.531	78	FeI(74)	0.486
80.720	33		
81.517	30	FeII(130)	0.510
82.403	13		
82.558	12	CeII(142)	0.524
83.308	43	FeII(14)	0.347
83.556	34	TmII(11) ?	
85.717	25	FeI(608)	0.706
85.948	30	FeI(177)	0.950
86.146	55	FeI(367)	0.176
86.31	85	TiII(12)	0.33
86.699	43	FeI(22)	0.678
87.207	33		
87.879	111	FeI(29)	0.883
88.293	3		
90.112	48	FeI(22)	0.095
90.481	21	CrI(139)	0.454
92.151	25	(FeI(287))	0.156
		(CrI(139))	0.137, FeI(367)
93.864	21	CrI(139)	0.879
94.620	29	CrI(139)	0.608
95.005	74	FeI(21)	0.004
3801.112	56		
01.744	33	FeI(367)	(0.681)
			(0.804)
02.047	38		
04.104	25		
04.796	27	CrI(137)	0.798
05.330	74	FeI(608)	0.345
05.763	3		
06.231	35	FeI(731)	0.203
06.762	103	MnI(6)	0.719, FeI(60)
07.150	59		
07.538	48	FeI(73)	0.534
08.718	46	FeI(222)	0.731
09.523	68	MnI(6)	0.592 ?
10.733	51	(TmII(9))	(0.724)
10.971	6		
11.858	48	FeI(287)	0.892
12.409	21		
12.994	103	(FeI(22))	0.964
		(FeI(222))	0.059
13.383	57	TiII(12)	0.390
13.649	28	FeI(283)	0.638
14.011	54	FeII(153)	0.121, CrII?
14.235	68	FeII(153)	0.121
14.572	99	(TiII(12))	0.580
		(FeI(22))	0.526
15.049	27		
15.428	48	CrI(71)	0.433
15.514	20		
15.854	140	FeI(45)	0.842
16.079	10		
16.348	44	FeI(73)	0.340
16.935	14	FeI(387)	0.92
17.628	54	FeI(701)	0.64
18.400	18		
19.544	69	CrI(70)	0.564 ?
20.420	128	FeI(20)	0.428
20.644	11		
21.163	64	FeI(608)	0.181
21.898	91	FeI(222)	0.834
23.503	34	CrI(24)	0.522
24.138	37		
24.420	132	FeI(4)	0.444
24.931	48	FeII(24)	0.913
25.008	1		
25.370	35	CrI(70)	0.390
25.889	97	FeI(20)	0.884
26.378	15	CrI(70)	0.425
27.038	0		
27.067	32	FeII(153)	0.079
27.830	102	FeI(45)	0.825
29.350	137	MgI(3)	0.355

Measured wavelength	W_λ(mÅ)	Identification	Laboratory wavelength
3830.370	0		
32.277	113	MgI(3)	(0.299)
			(0.303)
33.826	2	MnI(10)	0.862
34.154	44	FeI(20)	0.225
35.390	121	Core H9	0.297
38.280	142	MgI(3)	0.244
39.824	20	MnI(6)	0.777
40.436	48	FeI(20)	0.439
41.040	71	FeI(45)	0.051, NiI(6)
41.322	36	CrI(69)	0.277
41.993	16	CrI(70)	0.03
43.263	42	FeI(528)	0.259
44.143	29		
45.169	44	FeI(124)	0.170
45.479	32	CoI(34)	
46.377	39	FeI(804)	0.412
46.797	51	FeI(664)	0.803
47.470	12		
48.227	26		
49.017	12	CrI(69)	0.983
49.332	34		
49.570	43	CrI(24)	0.534, NiII(11)
49.980	98	(CrI(69))	0.042
		(FeI(20))	0.969
50.810	53	FeI(22)	0.820
52.272	20	CrI(24)	0.218
52.563	27	FeI(73)	0.574
53.135	20	CrI(69)	0.176
53.385	22	FeI(429)	0.462
53.659	66	SiII(1)	0.657
54.180	28	CrI(69)	0.220
54.302	47	CrI(69)	
55.321	39	CrI(69)	0.286
55.523	54	CrI(69)	0.571
55.816	16		
55.904	(17)		
55.992	(51)		
56.008	(68)	SiII(1)	0.021
56.382	100	FeI(4)	0.373
57.614	2	CrI(69)	0.631
57.698	44		
58.314	71	NiI(72)	0.301
58.904	61		
59.212	52	FeI(175)	0.214
59.68	28		
59.908	134	FeI(4)	0.913
60.840	5		
61.054	6		
61.355	50	FeI(663)	0.341, FeI(283)
61.66	10	FeI(663)	0.60
61.950	20		
62.600	100	SiII(1)	0.592
63.165	1		
63.379	18	FeII(152)	0.413
63.700	47	FeI(280)	0.745
63.964	38	FeII(127, 152)	0.953
64.892	14	VI(7)	0.862
65.182	4		
65.561	104	CrII(167)	(0.59)major
		FeI(20)	(0.526)
66.000	61	CrII(130)	0.01
66.310	1		
66.537	55	CrII(130)	0.54
66.810	15		
67.208	62	FeI(488)	0.219
67.985	21		
68.264	11	FeI(430)	0.243
69.588	47	FeI(284)	0.562, 0.590
70.146	36		
70.471	28		
70.814	37		
71.740	43	FeI(429)	0.750
72.534	81	FeI(20)	0.504
72.787	57	FeI(29)	0.76
72.863	24		
73.188	27		
73.759	44	FeI(175)	0.763
73.980	25		
74.506	28		
75.090	27	VI(7)	0.075
75.764	17		
76.067	23	FeI(22)	0.043
76.849	2		
77.404	9		
78.019	83	FeI(20)	0.021
78.282	47		
78.626	157	FeI(4)	0.575, FeI(17)
78.947	13		
79.174	19		
82.309	38	TiII(34)	0.28
83.298	53	(CrI(23))	0.292
		(FeI(663))	0.282
84.552	26		
85.104	31	(FeI(430))	0.54
		(CrI(23))	0.218
86.330	73	FeI(4)	0.284
87.060	50	FeI(20)	0.051
89.004	141		
93.353	33	FeI(430)	0.391
94.051	45	CoI(34)	0.073
		CrI(23)	0.035
95.208	20		
95.647	60	FeI(4)	0.658
96.126	35		
97.393	5		
97.606	5		
97.832	17	FeI(280)	0.896

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TABLE 1 - Continued

Measured wavelength	W$_\lambda$(mA)	Identification	Laboratory wavelength
3898.072	16	FeI(20)	0.012
98.572	102		
99.071	33	FeI(175)	0.037
99.300	39		
99.712	76	FeI(4)	0.709
3900.537	103	TiII(34)	0.546
3900.835	30	TmII(9)	0.790
02.085	5		
02.218	11	VI(7)	0.250
02.439	5		
02.941	102	CrI(23)	(0.915)
		FeI(45)	(0.948)
03.836	102	FeI(429)	0.902
04.721	22		
05.572	144	SiI(3)	0.527
		CrII(167)	0.64
06.032	50	FeII(173)	0.037
06.302	5		
06.484	55	FeI(4)	0.482
06.756	30	FeI(664)	0.748
06.891	5		
07.247	11		
07.404	15		
07.706	5		
07.965	68	FeI(280)	0.937
08.065	4		
08.330	13		
08.761	48	CrI(23)	0.755
09.245	18	CrII(129)	0.250
09.635	32		
09.876	56	FeI(364)	0.830
10.889	41	FeI(284)	0.845
11.314	59	CrII(129)	0.32
12.016	66		
13.467	150	TiII(34)	0.464
13.673	79	FeI(120)	0.635
14.270	97	FeI(467)	0.273
14.520	69	FeII(3)	0.480
15.318	75		
15.504	22		
15.858	35	CrI(136)	0.843
16.196	29	CrI(23)	0.243
16.380	83		
16.748	53	FeI(606)	0.733
17.190	61	FeI(20)	0.185
18.374	(68)	FeI(364)	0.418
18.628	(60)	FeI(430)	0.644
18.681	(65)		
19.110	96	(FeI(430))	0.069
		(CrI(23))	0.159
20.313	79	FeI(4)	0.260
20.614	55		
20.827	31	FeI(567)	0.839
21.064	80	CrI(23)	0.022
22.054	18		
22.928	102	FeI(4)	0.914
25.211	46	FeI(567)	0.201
25.654	59	FeI(364)	0.646
25.987	95	FeI(364)	0.946
26.718	36		
28.001	136	FeI(4)	0.922
28.653	45	CrI(23)	0.636
29.254	45		
29.713	15		
30.313	72	FeI(4)	0.299
31.146	14		
32.038	67	TiII(34)?	0.007
32.977	2		
33.293	3		
33.669	(148)	CaII(1)	0.664
35.859	41	FeII(173)	0.942
36.887	9		
37.335	29	FeI(278)	0.329
38.357	119	FeII(3)	0.289
38.991	62	FeII(190)	0.969, FeI(731)
40.927	31	FeI(20)	0.882
41.333	60	FeI(562)	0.283
41.496	33	CrI(23)	0.490
42.430	53	FeI(364)	0.443
43.125	27		
43.646	13		
44.055	49		
44.971	53		
45.172	96	FeII(3)	0.21
45.974	6	CrI(134)	0.968
46.400	5		
47.002	47	FeI(561)	0.002
47.530	58	FeI(361,426)	0.533
48.096	55	FeI(562)	0.105
48.772	73	FeI(604)	0.779
49.143	32	FeI(730)	0.14
49.946	52	FeI(72)	0.954
50.502	18		
51.143	76	FeI(661)	0.164
52.358	30	CrI(136)	0.399
52.645	25	FeI(278)	0.606
53.151	90	FeI(430)	(0.156)
		CrI(136)	(0.163)
53.75	58		
55.317	12	FeI(562)	0.352, FeI(188)
55.951	122		
56.436	20	FeI(604)	0.459
56.698	69	FeI(278)	0.681
57.034	64	FeI(562)	0.027
57.485	57		
58.212	8		
59.930	5		
60.430	5		

Measured wavelength	W$_\lambda$(mA)	Identification	Laboratory wavelength
3960.509	5		
61.151	12	FeI(361)	0.147
61.684	13		
62.693	4	FeI(913)?	
63.304	14		
63.679	42	CrI(38)	0.690
66.104	15	FeI(45)	0.066
66.614	11	FeI(562)	0.630
68.448	123	CaII(1)	0.470
69.929	12		
71.790	2		
72.452	5		
73.152	3		
73.676	9	FeI(769)	0.655
74.126	9	FeII(29)	0.160
75.987	6	CrI(38)	0.01
76.664	77	CrI(38)	0.665
77.754	24	FeI(72)	0.743
78.631	18	CrI(67)	0.677
79.516	57	CrII(183)	0.51
81.894	39		
82.069	50		
83.915	86	(FeI(277))	0.960
		(CrI(38))	0.907
84.277	30	CrI(38)	0.338
84.651	5		
84.731	9		
85.364	27	FeI(661)	0.393
85.991	22		
86.211	33	FeI(655)	0.176
86.773	65	MgI(17)	0.753
87.624	32		
89.023	48		
89.873	77	FeI(768)	0.859
90.369	31	FeI(527)	0.379
91.140	54	(CrI(38))	0.123
		(ZrII(30))	0.14
91.671	31	CrI(38)	0.673
92.108	22	CrI(38)	0.11
92.825	29	CrI(67)	0.845
93.091	10		
94.072	43	FeI(526)	0.117
95.298	77	MnII ?	
95.968	37	FeI(279)	0.996
96.221	10		
96.331	18		
96.96	39	FeI(945)	0.968
97.431	96	FeI(278)	0.394
98.053	64	FeI(276)	0.054
98.384	3		
98.604	25		
98.904	20		
99.610	7		
4000.188	19		
4000.464	35	FeI(426)	0.466
01.117	7		
01.444	38		
01.649	34	FeI(72)	0.666
02.067	55	FeII(29)	0.073
02.524	87	FeII(190)	0.549
02.938	35		
03.277	57	CrII(194)	0.33
03.743	36	FeI(728)	0.764
04.118	6		
04.904	132		
05.261	117	FeI(43)	0.246
05.810	17		
06.298	37	FeI(603)	0.314
06.692	96	FeI(488)	+ other
07.286	54	FeI(277)	0.277
07.84	22		
08.09	14		
08.867	63		
09.126	27		
09.703	67	FeI(72)	0.714
10.530	61		
10.928	30		
11.407	20	FeI(218)	0.416
12.462	169	CrII(183)	0.50, TiII(11)?
12.78	20		
13.11	12		
13.592	35		
13.824	57		
14.189	9		
14.555	76	FeI(802)	0.534
15.552	102	NiII(13)	0.50
16.426	37	FeI(560)	0.432
17.140	78	FeI(427)	0.156
17.513	58		
18.071	75	MnI(5)	0.102
18.272	70	FeI(560)	0.282
20.314	39		
20.490	16	FeI(913)?	
20.892	17	CoI(16)?	0.898
21.882	68	FeI(278)	0.869
22.349	44	CrII(183)	0.36
22.796	10		
23.404	13		
24.18	15		
24.552	98	FeII(127)	0.552
24.780	85	FeI(560)	0.735
25.139	97	(CrI(37))	0.012
		(TiII(11))	0.136?
25.517	42	CrI(37)	0.44?
25.823	45		
26.152	31	CrI(37)	0.166
26.494	24		
26.996	28	CrI(37)	0.103

Measured wavelength	W_λ(mA)	Identification	Laboratory wavelength	Measured wavelength	W_λ(mA)	Identification	Laboratory wavelength
4027.298	19			4087.32	17		
28.362	127	TiII(87)	0.332	87.609	30	CrII(19)	0.63
28.739	19			88.818	38	CrII(19)	0.90
29.668	85	FeI(556,563)	0.640, TiII(89)	89.209	11	FeI(422)	0.225
30.444	109	FeI(560)	0.499	89.511	30	CrII(164)	0.49
30.773	179	MnI(2)	0.775	93.01	7		
31.076	19			93.32	7		
31.479	50			97.172	15		
31.706	24			98.573	17		
31.984	65	FeI(655)	0.968	4101.737			
32.462	66			07.523	13	FeI(352)	0.492
32.665	71	FeI(44)	0.636	08.433	2		
33.034	183	MnI(2)	0.073	09.037	3	FeI(558)	0.070
34.180	20			09.550	39		
34.495	120	MnI(2)	0.490	10.290	2		
35.651	94	MnI(5)	0.728	10.961	97	(CrII(18))	0.01
37.145	23					(CrII(26))	0.01
37.984	84	CrII(194)	0.03	11.590	20		
38.757	58			11.808	22	FeII(21)	0.80
39.104	67			12.594	38	CrII(18)	0.59
40.083	51			12.961	44	FeI(1103)	0.972
40.259	9			13.237	50	CrII(18)	0.24
40.655	41	FeI(655)	0.650	14.137	5		
41.354	109	MnI(5)	0.361	14.476	28	FeI(357)	0.449
41.637	42			14.983	14	FeI(695)	0.957
43.965	94	FeI(276,557)	0.901	16.984	11	FeI(558)	0.97
44.575	64	FeI(359)	0.614	17.869	12	FeI(700,1103)	0.872
45.122	43			18.544	63	FeI(801)	0.549
45.616	69	ZrII(30)	0.63	18.868	44	FeI(559)	0.904
45.824	165	FeI(43)	0.815	19.527	31	FeII(21)	0.53
46.074	51	FeI(557)	0.07	20.221	25	FeI(423)	0.211
46.450	9			21.320	28		
46.882	15			21.823	33	FeI(356)	0.806
47.490	5			22.629	92	(FeI(356))	0.552
48.073	10					(FeII(28))	0.638
48.785	106	MnI(5)	0.755	23.228	11		
49.085	70	CrII(193)	0.14	23.775	22	FeI(422)	0.748
49.337	19	FeI(218)	0.336	24.608	5		
50.696	22			24.77	16	FeII(22)	0.793
51.228	25			25.638	30	FeI(1103)	0.622
51.932	112	CrII(19)	0.97	25.89	5	FeI(359)	0.884
52.436	59	FeI(563)	0.466	26.196	41	FeI(695)	0.192
52.690	27	FeI(557)	0.72	26.523	26		
53.345	39			27.130	36		
53.826	98	TiII(87)	0.814	27.612	44	FeI(357)	0.612
54.108	95	CrII(19)	0.11	27.790	41	FeI(558)	0.807
54.551	4			28.116	130	SiII(3)	0.053
54.822	82	FeI(698)	0.833	28.464	11		
55.058	44	FeI(218)	0.046	28.749	55	FeII(27)	0.735
55.548	60	MnI(5)	0.543	29.191	58	CrI(97)	0.21
56.081	54	CrII(182)	0.07	29.970	17	CrI(97)	0.96
57.514	112	MgI(16)	0.505	30.899	105	SiII(3)	0.884
57.953	12			31.353	14	CrI(261)	0.360
58.225	29	FeI(558)	0.227	32.053	95	FeI(43)	0.060
58.868	39	MnI(5)	0.930	32.473	86	CrII(26)	0.41
59.736	24	FeI(767)	0.726	32.917	40	FeI(357)	0.903
60.656	15			33.596	10		
61.110	19			33.858	41	FeI(698)	0.869
61.771	18	CrII(19)	0.77	34.426	23	FeI(482)	0.433
61.992	20			34.679	63	FeI(358)	0.681
62.465	39	FeI(359)	0.446	35.697	10	ZrI(50)	0.68
62.731	12			36.219	11		
63.291	34	FeI(698)	0.286	36.517	19	FeI(694)	0.512
63.604	119	FeI(43)	0.597	36.998	64	FeI(726)	0.002
64.071	45	FeI(423)	0.07	37.313	15	TiI(253)	0.284
64.400	27			37.400	16		
65.035	16			37.897	5		
65.385	8	FeI(698)	0.402	38.102	19		
65.710	10			38.349	37		
66.145	19	CrII(182)	0.16	39.015	9		
66.623	20			39.632	10		
67.008	100	FeI(358)	0.979	39.805	3		
67.273	35	FeI(217)	0.275	40.372	22		
67.990	73	MnI(5)	0.103	41.740	14		
68.334	5			42.187	24	NiI(212)	0.184
68.969	10	TiI(299)	0.981	42.520	25		
69.522	10			43.451	91	FeI(523)	0.418
69.893	24	FeII(188)	0.883	43.876	94	FeI(43)	0.871
70.811	89	FeI(558)	0.766	44.366	5		
71.494	16	CrII(193)		45.136	13		
		FeI(218)	0.52	45.766	69	CrII(162)	0.77
71.746	94	FeI(43)	0.740	46.049	28	FeI(422)	0.071
72.547	67	FeI(195)	0.518	46.375	33		
		CrII(26)	0.56	46.961	26		
73.771	35	FeI(558)	0.760	47.331	28	FeI(693)	0.34
74.783	62	FeI(524)	0.794	47.666	57	FeI(42)	0.673
75.566	12			48.255	5	FeII(832p)	0.27
75.967	27	FeII(21)	0.95	49.381	72	FeI(694)	0.372
76.611	52	FeI(558)	0.636	50.231	44	FeI(695)	0.258
76.857	94	CrII(19)	0.87	50.563	16	TiI(253)	0.557
77.520	44	CrII(19)	0.50	50.995	54	CrII(163)	0.00
77.726	115	SrII(1)	0.714	52.080	80		
78.375	26	FeI(217)	0.365	53.874	105	FeI(695)	0.906
79.196	25	MnI(5)	0.241	54.121	37	FeI(694)	0.109
79.360	25	MnI(5)	0.422	54.487	83	FeI(355)	0.502
79.853	24	FeI(359)	0.848	54.791	86	FeI(694)	0.812
80.211	26	FeI(558)	0.226	55.279	3		
80.343	5			55.977	11		
80.842	5	FeI(557)	0.886	56.330	69		
81.28	10			56.771	74	FeI(354)	0.803
82.330	39	CrII(165)	0.30	57.778	77	FeI(695)	0.788
82.934	10	MnI(5)	0.944	58.257	15		
83.664	77	MnII ?		58.772	75	FeI(695)	0.798
84.503	33	FeI(698)	0.498	59.140	87		
85.000	31	FeI(358)	0.011	60.323	41		
85.222	47	FeI(559)	0.312	60.645	34	FeI(689)	0.625
86.132	42	CrII(26)	0.14	61.082	55	FeI(689)	0.080
87.174	17						

TABLE 1–Continued

TABLE 1-Continued

Measured wavelength	W_λ(mA)	Identification	Laboratory wavelength	Measured wavelength	W_λ(mA)	Identification	Laboratory wavelength
4161.463	86	TiII(21)	0.524	4222.202	83	FeI(152)	0.219
61.807	29	SrII(3)	0.796	24.156	92	FeI(689)	0.176
63.633	132	TiII(105)	0.644	24.514	59	FeI(689)	0.509
65.38	33			24.837	89	CrII(162)	0.85
65.494	46	CrI(305)	0.519	25.458	71	FeI(693)	0.460
67.281	95	MgI(15)	0.27	25.70	30		
67.921	36	FeI(599)	0.862	25.943	36	FeI(521)	0.956
68.665	53	FeI(689)	0.625	26.390	44	FeI(352)	0.426
68.955	17	FeI(694)	0.942	26.714	153	CrI(2)	0.728
69.799	36	FeI(693)	0.777	27.385	153	FeI(693)	0.434
70.158	13	CrI(278)	0.202	29.446	29	FeI(416,649)	0.516
70.626	49	CrII(18)	0.58	29.790	40	FeI(41)	0.760
70.972	95	FeI(482)	0.906	30.449	13	CrI(132)	0.481
71.661	46	FeI(941)	0.696	30.937	2.		
71.925	130	TiII(105)	0.897	31.842	28		
72.114	96	FeI(649)	0.126	33.171	210	FeII(27)	0.167
72.692	105	FeI(689)	0.641	33.598	105	FeI(152)	0.608
73.493	171	FeII(27)	0.450	35.304	32	MnI(23)	0.290
74.096	50	TiII(105)	0.088	35.914	120	FeI(152)	0.942
74.350	61	MnII?		36.365	50	CrII(12)	0.33
74.874	56	FeI(19)	0.917	37.266	25		
75.23	7			37.987	65	FeI(689)	0.027
75.631	73	FeI(354)	0.640	38.800	129	FeI(693)	0.816
76.067	26			38.84	16		
76.577	89	FeI(695)	0.571	39.02	16		
77.651	112	FeI(18)	0.597	39.809	61	FeI(273)	0.847 Blend
78.075	34						
78.511	10			40.374	51	FeI(764)	0.372
78.857	136	FeII(28)	0.855	40.667	22	CrI(105)	0.705
79.379	149	CrII(26)	0.43	41.032	8		
80.47	9			41.470	8.		
80.98	13			42.371	140	CrII(31)	0.38
81.744	102	FeI(354)	0.758	42.675	29		
81.999	77			43.412	10		
82.385	52	FeI(476)	0.384	43.704	12		
82.732	33	FeI(694)	0.790	44.224	12	MnII(7)	0.26
83.153	10	FeII(21)	0.20	44.817	12	NiII(9)	0.80
83.317	10			45.302	76	FeI(352)	0.258
83.493	16	VII(37)	0.435	46.044	17	FeI(906)	0.090
83.989	87			46.386	49	CrII(31)	0.41
84.334	76			46.846	80	SiII(7)	0.829
84.887	73	FeI(335)	0.895	47.421	94	FeI(693)	0.432
87.046	97	FeI(152)	0.044	48.232	56	FeI(482)	0.228
87.588	49	FeI(694)	0.59	50.135	109	FeI(152)	0.125
87.823	139	FeI(152)	0.802	50.438	38		
88.747	96			50.804	125	FeI(42)	0.790
89.533	19	FeI(940)	0.564	51.726	23	GdII(15)	0.733?MnII? 0.70
90.131	29	CrI(84)	0.16	52.20	10	CrI(131)	0.243
91.416	103	FeI(152)	0.436	52.631	99	CrII(31)	0.62
91.694	64	FeI(355)	0.685	53.010	32	MnII(7)	0.02
92.061	30	NiII(10)	0.07	54.341	120	CrI(1)	0.346
93.652	22	CrI(248)	0.662	54.52	81		
95.066	18			55.495	23	CrI(105)	0.502
95.354	129	FeI(693)	0.337	56.132	42	CrII(192)	0.16
95.624	31	FeI(478)	0.615	56.67	7	CrI(131)	0.620
96.209	72	FeI(693)	0.218	57.35	9	CrI(131)	0.368
96.481	16			57.59	9		
97.171	19			58.133	84	FeII(28)	0.155
98.068	75			58.337	54	FeI(3)	0.320
98.292	139	FeI(152)	0.310	58.719	13		
98.647	70	FeI(693)	0.645	59.04	11	FeI(419)	0.956
99.092	106	FeI(522)	0.098	59.258	53		
99.474	33			60.069	66		
99.851	30			60.476	136	FeI(152)	0.479
4200.021	10	FeI(993)	0.09	61.266	19		
4200.557	24			61.914	154	CrII(31)	0.92
4200.931	61	FeI(689)	0.930	62.289	9		
01.440	5			62.716	5		
02.031	122	FeI(52)	0.031	63.143	38	CrI(247)	0.141
02.559	40			63.861	32		
02.746	30	FeI(476a, 521)	0.755	64.201	34	FeI(692)	0.209
03.580	15	CrI(35)	0.590	64.756	12	FeI(993)	0.743
03.963	88	FeI(355)	0.987	65.269	31	FeI(993)	0.260
04.46	16	CrI(272)	0.471	66.037	13		
05.096	30	VII(37)	0.080	66.967	32	FeI(273)	0.968
05.33	88			67.815	43	FeI(482)	0.830
05.480	66	(FeI(089))	0.546	68.837	42	CrI(271)	0.788
		(FeII(22))	0.48	69.278	96	CrII(31)	0.28
06.282	27			71.151	118	FeII(152)	0.159
06.54	51			71.779	143	FeI(42)	0.764
06.785	16			73.304	86	FeII(27)	0.317
07.131	50	FeI(352)	0.130	74.798	136	CrI(1)	0.803
07.391	82	CrII(26)	0.35	75.570	119	CrII(31)	0.57
07.85	14			75.978	21	CrI(240)	0.973
08.633	62	FeI(689)	0.610	76.673	21	FeI(976)	0.684
09.077	42	CrII(162)	0.02	77.567	15		
09.36	27	CrI(248)	0.368	78.163	85		
09.606	23			78.637	7		
09.798	50			79.011	6		
10.364	98	FeI(152)	0.352	79.482	12	FeI(993)	0.480
11.002	16			79.888	4	ScII(15)	0.927
11.27	7			80.384	51	CrI(247)	0.405
11.76	10			81.060	31	CrII(17)	0.03
12.60	2			81.905	4		
13.14	6			82.436	96	FeI(71)	0.406
13.610	55	FeI(355)	0.650	83.007	87	CaI(5)	0.010
15.501	162	SrII(1)	0.525	83.756	19	MnII(6)	0.772
15.760	68	CrII(18)	0.77	84.206	102	CrII(31)	0.21
16.273	43	FeI(3)	0.186	84.42	15	FeI(417)	0.415
		CrI(132)	0.315	84.916	6		
17.065	57	CrII(18)	0.07	85.424	51	FeI(597)	0.445
17.556	92	FeI(693)	0.551	85.862	5	FeI(904)	0.832
17.841	10			86.287	8	FeII(n)	0.311
18.145	16			86.45	11	FeI(414)	0.440
19.394	100	FeI(800)	0.364	86.988	33	FeI(976)	0.976
20.061	61			87.874	94	TiII(20)	0.893
20.359	42	FeI(482)	0.347	88.121	26	FeI(273)	0.148
21.984	35	CrII(180)	0.00	89.060	7		

TABLE 1-Continued

Measured wavelength	W_λ (mA)	Identification	Laboratory wavelength	Measured wavelength	W_λ (mA)	Identification	Laboratory wavelength
4289.369	81	CaI(5)	0.364	4373.564	36	FeI(214, 413)	0.563
89.702	127	CrI(1)	0.721	74.158	31	CrI(104)	0.158
90.259	140	TiII(41)	0.222	74.490	50	ScII(14)	0.455
90.951	15	TiI(44)	0.433	74.890	89	TiII(93)	0.825
91.504	14	FeI(41)	0.466	75.361	25	TiII(104)	0.35
91.97	14	CrI(240)	0.964	75.931	55	FeI(2)	0.932
92.244	46	(FeI(70p))	0.13	76.776	32	FeI(471, 904)	0.782
		(FeI(70))	0.293	77.441	14		
93.059	5			77.835	4		
93.543	6	CrI(96)	0.565	78.536	5		
94.096	163	FeI(41)	0.128	79.064	5		
		TiII(20)	0.101	79.827	7		
94.722	5	ScII(15)	0.767	80.589	7		
95.288	9			80.859	13		
95.785	27			81.240	13		
96.575	92	FeII(28)	0.567	81.843	5		
97.074	2			82.471	12		
97.740	22	CrI(247)	0.738	82.692	32		
98.038	37	FeI(520)	0.040	83.534	137	FeI(41)	0.547
98.651	2	TiI(44)	0.664	83.961	25		
98.991	67	CaI(5)	0.986	84.303	70		
99.251	98	FeI(152)	0.242	84.693	35	MgII(10)	0.643
99.631	22			84.980	35	CrI(22)	0.477
4300.050	143	TiII(41)	0.052	85.373	99	FeII(27)	0.373
4300.496	22	TiI(44)	0.566	85.693	5		
01.184	27			86.184	3		
01.947	116	TiII(41)	0.928	86.582	10		
02.292	30	FeI(42)	0.031	86.841	61	TiII(104)	0.858
		FeI(520)	0.191	87.434	10.		
02.527	97	CaI(5)	0.527	87.892	36	FeI(476)	0.897
03.178	121	FeII(27)	0.166	88.393	42	FeI(830)	0.412
03.572	5	NdII(10)	0.573	89.313	2		
04.162	7	VII(213)??		90.130	5		
04.504	10	FeI(414)	0.552	90.550	33	MgII(10)	0.585
05.20	9	FeI(760)	0.20	90.992	69	FeI(414)	0.954
05.451	64	FeI(476)	0.455	91.780	41		
05.803	17	ScII(15)	0.715	92.58	14		
06.911	57			93.277	15		
07.834	170	CaI(5)	0.741	94.055	72	TiII(51)	0.057
		TiII(41)	0.900	95.011	131	TiII(19)	0.031
		FeI(42)	0.906	95.46	13		
09.062	40	FeI(849)	0.036	95.825	70	TiII(61)	0.848
09.395	51	FeI(414)	0.382	97.352	4		
09.710	33			97.91	9		
10.048	1			98.274	25	TiII(61)	0.314
10.457	11			99.457	97	TiII(51)	0.767
12.444	5	CrI(177)	0.469	4400.374	25	ScII(14)	0.355
12.888	124	TiII(41)	0.861	4400.620	11	TiII(93)	0.63
13.765	5			4400.940	20		
14.086	41	ScII(15)	0.084	01.272	38	FeI(828)	0.293
14.307	76	FeII(32)	0.289	01.476	22	FeI(350)	0.447
15.025	165	TiII(41)	0.979	02.907	35	FeII(u)	0.875
15.450	8	FeI(71)	0.087	03.116	17		
16.809	62	TiII(94)	0.807	03.473	28		
17.942	5			04.743	119	FeI(41)	0.742
18.152	14			06.74	12		
18.677	71	CaI(5)	0.652	07.699	72	(TiII(51))	0.678
19.443	17					(FeI(68))	0.714
19.691	45	FeII(220)	0.717	08.405	49	FeI(68)	0.419
20.749	54	ScII(14)	0.745	08.74	2		
20.964	70	TiII(41)	0.965	09.197	30	TiII(61)	0.22
21.34	21	FeII(220)	0.341	09.539	41	TiII(61)	0.519
21.77	14			10.162	8		
25.033	68	CnI(104)	0.075	11.044	64	TiII(115)	0.080
		ScII(15)	0.010	11.35	1		
25.464	58			11.963	34	TiII(61)	0.936
25.787	128	FeI(42)	0.765	12.185	6	CrI(22)	0.250
26.688	70			12.470	5	FeI(69)	0.43
27.115	33	FeI(761)	0.100	13.573	43	FeII(32)	0.600
30.266	44	TiII(94)	0.264	13.743	13		
30.728	63	TiII(41)	0.708	14.776	22	MnI(22)	0.879
37.112	22	FeI(41)	0.049	15.120	94	FeI(41)	0.125
37.503	33	CrI(22)	0.566	15.545	20	ScII(14)	0.559
37.927	71	TiII(20)	0.916	15.965	2		
40.522	89	H		16.820	100	FeII(27)	0.817
44.002	54	MnII(6)	0.987	17.724	90	TiII(40)	0.718
44.295	34	TiII(20)	0.291	18.343	60	TiII(51)	0.340
44.518	36	CrI(22)	0.507	18.916	25	GdII(15)	0.032
46.592	20	FeI(598)	0.558	21.957	53	TiII(93)	0.941
46.851	39	CrI(104)	0.833	22.473	65	FeI(350)	0.570
47.375	5			22.947	22	FeI(646)	0.882
47.770	19			23.288	42	TiII(61)	0,22
48.343	32			23.873	15	FeII(830)	0.858
50.861	30	TiII(94)	0.834	24.273	16	CrI(129)	0.281
51.068	24	CrI(22)	0.051	25.429	60	CaI(4)	0.441
51.558	14	FeI(413)	0.549	27.313	54	FeI(2)	0.312
51.869	178	FeII(27)	0.764	27.909	15	TiII(61)	0.90
52.707	73	FeI(71)	0.737	28.475	11	VI(921)	0.515
53.262	1			29.237	5	CeII(19)	0.270
54.314	25	FeII(213)	0.358	30.076	32		
55.091	37	CaI(37)	0.096	30.511	50	FeI(68)	0.618
57.586	36	FeII(u)	0.574	31.641	15	FeII(222)	0.626
58.493	30	FeI(412)	0.505	31.806	19		
59.642	55	CrI(22)	0.631	32.153	34	TiII(51)	0.089
60.754	13			32.661	14		
61.270	27	FeII(u)	0.249	33.227	49	FeI(830)	0.223
62.083	25	NiII(9)	0.10	33.758	27	FeI(825)	0.793
62.423	16			34.028	22	TiI(113)	0.003
62.932	46	CrII(179)	0.93	34.977	71	CaI(4)	0.960
66.107	15			35.23	16	FeI(2)	0.151
67.641	118	FeI(414)	0.581	35.691	57	CaI(4)	0.688
		TiII(104)	0.657	36.087	6	VI(21)	0.087
67.934	17	FeI(41)	0.906	36.407	6	MuI(22)	0.352
68.138	61			36.918	8	FeI(516)	0.931
68.533	6			37.828	5	VI(21)	0.837
68.904	5	TiI(245)	0.941	38.364	12	FeI(828)	0.353
69.422	56	FeII(28)	0.404	40.460	15	FeI(829)	0.479
69.799	62	FeI(518)	0.774	40.829	9	FeI(992)	0.840
71.060	17						
71.310	57	CrI(22)	0.279				

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TABLE 1-Continued

Measured wavelength	W_λ(mA)	Identification	Laboratory wavelength	Measured wavelength	W_λ(mA)	Identification	Laboratory wavelength
4441.124	12			4503.935	2		
41.751	45	TiII(40)	0.73	04.421	6		
42.364	60	FeI(68)	0.343	04.558	16		
42.83	8	FeI(69)	0.835	04.74	9		
43.188	45	FeI(350)	0.197	06.859	19	CrI(288)	0.853
43.77	122	TiII(19)	0.802	07.161	32		
44.320	11	CeII(19)	0.393	08.268	105	FeII(38)	0.283
44.541	55	TiII(31)	0.559	09.727	16		
45.183	8			10.545	11		
46.255	25	FeII(187)	0.248	11.813	36		
46.860	23	FeI(828)	0.842	13.245	6		
47.130	11	FeI(69)	0.134	14.128	14	FeI(514)	0.189
47.742	60	FeI(68)	0.722	14.429	34	CrI(287)	0.373
48.6	2			15.319	103	FeII(37)	0.337
49.624	22	FeII(222)	0.663	15.553	33	CrI(126)	0.440
50.494	78	TiII(19)	0.487	15.825	24		
50.9	2			16.639	14		
51.567	57	MnI(22)	0.586	17.150	10		
		FeII(n)	0.545	17.499	18		
51.996	2	VI(87)	0.008	17.96	5		
52.7	2			18.314	29		
53.0	2	MnI(22)	0.005	20.212	93	FeII(37)	0.225
53.286	16	TiI(113)	0.312	21.099	11	CrI(287)	0.141
54.378	38	FeI(350)	0.383	22.629	115	FeII(38)	0.634
54.763	82	CaI(4)	0.781	23.414	13	FeI(829)	0.403
54.989	27	(FeI(474))	0.135	24.749	14	TiII(60)	0.732
		(MnI(28))	0.012	25.148	54	FeI(826)	0.142
55.273	48	MnI(28)	0.318	26.092	7	CrI(196)	0.108
55.881	58	(MnI(28))	0.821	26.443	68	CrI(33)	0.466
		(CaI(4))	0.887	26.910	25		
56.425	7			27.360	22	CrI(33)	0.339
56.638	34	CaI(4)	0.612	28.621	77	FeI(628)	0.619
57.0	7	MnI(28)	0.045	29.502	81	TiII(82)	0.465
57.466	19	MnI(28)	0.549	30.704	40	CrI(33)	0.688
58.100	22	MnI(28)	0.262				0.755
58.537	26	CrI(127)	0.538	31.133	34	FeI(39)	0.152
59.090	61	FeI(68)	0.121	31.750	13'	FeI(555)	0.663
59.322	33			32.999	30	CrI(212)	0.75
59.7	14	CrI(127)	0.738	33.235	23	TiI(42)	0.238
61.155	17	MnI(28)	0.085	33.974	116	TiII(50)	0.966
61.423	43			34.172	68	FeII(37)	0.166
61.682	58	FeI(2)	0.654	34.780	12	TiI(42)	0.782
61.991	52	MnI(28)62	0.022	35.118	14	CrI(33)	0.146
62.385	1	VI(87)	0.363	35.680	43	TiI(42)	0.574
63.342	10			36.250	5		
64.443	61	TiII(40)	0.458	38.575	15		
64.609	33	CrI(127)	0.669	39.577	60	CrII(39)	0.62
65.072	11	CrI(1127)	4.909	39.748	27	CrI(33)	0.788
65.339	11	CrI(127)	0.357	40.535	30	CrI(33)	0.502
65.727	26	CrII(191)	0.78	40.749	34	CrII(150)	0.719
66.561	70	FeI(350)	0.554	40.071	18	CrI(33)	0.071
66.828	11	FeI(992)	0.939	41.497	68	FeII(38)	0.523
67.9	7			42.520	11	FeI(894)	0.422
68.490	27	TiII(31)	0.493	42.820	7	CrI(19)	0.621
69.195	33			43.044	28		
69.395	53	FeI(830)	0.381	44.628	40	CrI(33)	0.619
70.495	11			45.138	40		
70.860	44	TiII(40)	0.864	45.525	9	CrI(33)	0.335
71.234	17			45.953	34	CrI(10)	0.895
72.937	55	FeII(37)	0.921	46.666	10		
74.261	19	FeII(171)	0.194	46.076	10	FeI(39)	0.022
74.556	9			47.864	37		
79.8	2	TiI(113)	0.852	49.193	53	FeII(186)	0.214
75.343	9			49.551	153	FeII(38)	0.467
76.066	88	FeI(830)	0.082	49.830	55	TiII(82)	0.622
		FeI(350)	0.021	50.791	43		
78.651	13	GdII(15)	0.795	52.288	28		
79.340	2			52.483	14	TiI(42)	0.453
79.637	19	FeI(828)	0.612	53.028	78	BaII(1)	0.033
80.236	21	CrI(197)	0.263	54.013	95	CrII(44)	0.02
80.730	30			55.887	102	FeII(37)	0.890
81.127	177	MgII(4)	0.129	56.139	56	FeI(820)	0.129
81.334	174	MgII(4)	0.327	57.285	14		
81.662	28			58.13	5	FeI(894)	0.108
82.230	65	FeI(68)	0.257	58.676	141	CrII(44)	0.659
82.773	24	CrI(197)	0.878	59.532	0		
84.228	43	FeI(828)	0.227	60.099	9	FeI(823)	0.096
85.678	28	FeI(830)	0.679	61.193	5		
87.523	22			61.499	10	CrI(277)	0.54
88.333	21	TiII(115)	0.319	62.53	3		
88.441	70			63.23	7	CrI(296)	0.245
89.172	100	FeII(37)	0.185	63.789	64	TiII(50)	0.761
89.480	20			64.127	15	CrI(312)	0.166
89.811	16	FeI(2)	0.741	64.585	30		
90.082	29	MnI(22)	0.081	65.584	31	CrI(21)	0.512
90.751	30	FeI(974)	0.773	65.740	91	CrII(39)	0.78
91.408	86	FeII(37)	0.401	66.539	10	FeI(841)	0.520
91.824	2			66.924	22		
92.311	13	CrI(197)	0.312	68.275	22		
92.742	10	FeI(964)	0.693	68.782	7	FeI(554)	0.789
93.535	39	FeII(222)	0.579	69.200	2		
94.025	15			69.602	17	CrI(173)	0.530
94.586	59	FeI(68)	0.568				0.644
95.441	7	FeI(314,470)	0.386	71.194	22	CrI(125)	0.105
95.908	11			71.676	16	CrI(32)	0.671
96.252	2			71.992	124	TiII(82)	0.971
96.878	50	CrI(10)	0.862	72.503	5		
98.737	13	MnI(22)	0.897	72.817	5		
99.304	21			73.621	5		
99.668	17			74.278	5	FeI(554)	0.240
4500.386	80	CrI(150)	0.295	75.178	2		
01.297	106	TiII(31)	0.270	75.786	5		
01.763	12	CrI(81)	0.788	76.356	74	FeII(38)	0.331
02.304	10	MnI(22)	0.220	77.070	5		
02.746	3			77.43	5		
03.065	5			77.970	8		
03.535	1			78.576	30	CaI(23)	0.558
03.735	2	TiI(184)	0.762	78.907	2		

TABLE 1-Continued

Measured wavelength	W_λ(mA)	Identification	Laboratory wavelength
4579.751	33		
80.061	66	(CrI(10))	0.056
80.509	20		
81.433	47	CaI(23)	0.402
81.916	7		
82.403	5		
82.862	63	FeII(37)	0.835
83.441	27		
83.872	123	FeII(38)	0.829
84.863	19	CrI(125)	0.75
85.43	9		
85.923	46	CaI(23)	0.871
86.323	14	CrI(173)	0.138
87.252	28	FeI(295)	0.132
88.220	134	CrII(44)	0.217
89.633	1		
89.967	111	CrII(44)	0.89
90.833	7	CrI(125)	0.69
91.441	31	CrI(21)	0.394
92.074	104	CrII(44)	0.09
92.588	31	FeI(39)	0.655
93.500	3		
93.883	23		
95.666	31	CrI(286)	0.590
96.085	54	FeI(820)	0.059
97.368	14		
97.826	21		
98.126	25	FeI(554)	0.122
98.469	28		
99.829	18		
4600.230	15		
4600.729	42	CrI(21)	0.752
01.009	14	CrI(32)	0.021
01.407	14	FeII(43)	0.34
02.017	19	FeI(39)	0.005
02.978	39	FeI(39)	0.944
02.978	39	FeI(39)	0.944
04.575	15		
04.951	14		
05.387	11		
05.691	9		
06.230	6		
07.672	28	FeI(554)	0.655
09.33	7		
10.671	8		
11.273	37	FeI(826)	0.285
11.83	8		
13.298	27	CrI(21)	0.373
13.859	6		
14.706	10		
15.728	10		
16.169	42	CrI(21)	0.137
16.640	85	CrII(44)	0.64
18.038	5		
18.525	110	VII(252)	0.52
18.840	32	CrII(44)	0.83
19.286	26	FeI(821)	0.294
19.608	1	CrI(81)	0.551
20.272	55	FeII(37)	0.225
20.555	1	FeII(38)	0.513
21.110	9		
21.551	3		
21.931	30	CrI(32,244)	0.893
22.419	18		
22.855	3		
23.859	5		
24.267	5		
24.787	1		
25.033	6	FeI(554)	0.052
25.250	28		
25.500	8		
25.909	35	CrI(244)	0.925
26.292	37	CrI(21)	0.188
26.63	2		
26.83	5		
27.13	2		
28.165	5		
28.901	15		
29.361	83	FeII(37)	0.336
30.23	13	FeI(115)	0.125
31.003	10		
32.724	11		
34.091	95	CrII(44)	0.11
34.630	14		
35.365	52	FeII(186)	0.328
35.764	6		
36.365	8		
36.736	1		
37.302	6		
37.549	19	FeI(554)	0.512
37.868	7	TiII(261)	0.887
38.055	42	FeI(822)	0.016
38.936	6		
39.581	6		
40.261	13		
40.261	13		
40.795	20		
41.115	9		
43.485	24	FeI(820)	0.468
46.183	57	CrI(21)	0.174
46.661	29		
46.463	33	FeI(409)	0.437
48.227	21		
48.886	27		
49.414	21		
49.890	10		
51.287	29	CrI(21)	0.285
51.722	4		
4652.168	50	CrI(21)	0.158
52.773	2		
53.342	4		
54.174	14		
54.612	48	FeI(554) / FeI(821)	0.628 / 0.628
56.213	7		
56.500	7		
56.962	46	FeII(43)	0.974
57.432	41		
60.43	5		
60.93	11		
61.553	9	FeI(1207)	0.538
61.864	10		
62.701	6		
63.132	11		
63.294	28		
63.746	51	FeII(44)	0.700
64.793	24		
65.838	37		
66.170	22		
66.491	28		
66.788	64	FeII(37)	0.750
67.194	22		
67.482	44	FeI(822)	0.459
68.130	38	FeI(554)	0.142
69.284	32	FeI(821)	0.174
70.271	38		
71.403	24	CrII(178)	0.36
72.324	29		
72.63	14		
73.211	36	FeI(820)	0.169
74.143	17		
78.203	40		
78.870	40	FeI(821)	0.852
79.243	21		
80.454	16		
80.862	10	CrI(170)	0.870
81.594	3		
82.062	14		
84.759	26	CrII(78)	0.77
85.286	13	CaI(51)	0.265
86.223	8		
87.503	1		
88.166	19		
88.692	5		
89.360	21		
90.113	16	FeI(820)	0.146
91.290	34		
91.484	27	FeI(409)	0.414
93.841	12		
94.881	10		
97.098	9		
97.626	35	CrII(177)	0.62
98.555	36		
99.422	43		
4700.151	21	FeI(935)	0.171
01.635	22		
02.570	8		
03.017	89	MgI(11)	0.98
04.383	6		
04.913	13	FeI(821)	0.958
06.03	8		
06.53	9		
07.273	33	FeI(554)	0.281
07.995	28		
08.656	44		
09.122	24	FeI(821)	0.092
09.738	7	MnI(21)	0.715
10.290	18	FeI(409)	0.286
10.820	6		
13.220	19		
13.996	22		
14.409	38	NiI(98)	0.421
15.109	17	CrII(178)	0.12
17.596	15		
18.428	38		
20.547	21		
21.054	5		
23.138	10		
23.371	42		
24.469	10	CrI(145)	0.416
27.141	26		
27.441	38	FeI(821)	0.405
27.838	13	MnII	
28.544	35	FeI(822)	0.555
28.999	13		
29.386	21		
29.727	20		
30.390	18	MnII	
30.700	18	CrI(145)	0.711
31.028	16		
31.468	77	FeII(43)	0.439
32.471	4		
34.130	10		
35.854	20		
36.795	49	FeI(554)	0.780
37.038	36		
37.346	35	CrI(145)	0.350
37.615	6	VII(16)	0.59
38.309	22	MnII	
39.079	9	MnI(21)	0.108
40.463	13		
40.937	14		
41.481	24		
42.172	24		
44.318	29		
44.572	8		

TABLE 1-Continued

Measured wavelength	W_λ(mA)	Identification	Laboratory wavelength	Measured wavelength	W_λ(mA)	Identification	Laboratory wavelength
4745.811	20	FeI(821)	0.806	4891.564			
48.160	53			92.992			
49.846	12			93.337			
54.077	26			93.839			
54.062	46	MnI(16)	0.042				
54.751	10						
55.732	61						
56.128	48	CrI(145)	0.113				
56.554	4						
56.872	1						
57.353	13						
57.691	18						
61.507	38	MnI(21)	0.526				
62.352	44	MnI(21)	0.376				
62.831	40						
63.618	10						
63.935	55						
64.320	26						
64.710	62						
65.135	9						
65.519	27						
65.825	28	MnI(21)	0.859				
66.526	26						
67.352	20						
67.850	20						
68.425	28						
71.489	54						
72.824	21						
76.396	13						
80.027	76	TiII(92)	0.986				
80.897	8						
82.908	19						
83.174	56						
83.407	47	MnI(16)	0.420				
83.934	27						
84.425	1						
84.592	5						
85.171	1						
86.586	24	NiI(98)	0.541				
86.988	44						
87.309	1						
89.294	42						
89.574	27						
90.160	14						
90.884	9						
91.107	34						
91.794	8						
92.488	44						
93.149	6						
96.217	25						
98.559	44						
99.942	35						
4800.592	31						
4800.958	36						
02.917	25						
04.400	15						
04.600	20	FeI(721)	0.59				
05.100	105	TiII(92)	0.105				
06.830	27						
07.600	1						
08.682	26						
10.742	21						
12.350	83	CrII(30)	0.35				
15.374	12						
15.808	5						
20.713	7						
23.513	56	MnI(16)	0.516				
24.161	112	CrII(30)	0.13				
24.450	18						
24.772	5						
25.429	7	TiI(250)	0.445				
25.731	17						
26.711	24						
27.146	5						
27.614	16	TiI(250)	0.597				
29.354	43						
29.754	8						
30.601	5						
31.226	14						
33.147	27						
35.030	4						
35.924	9						
36.215	72	CrII(30)	0.22				
38.678	25						
40.307	46						
40.887	2						
48.254	88	CrII(30)	0.24				
61.380	83						
71.410	38						
72.196	33						
72.689	1						
73.504	8						
74.107	80						
79.553	1						
75.109	1						
75.510	5						
76.516	55	CrII(30)	0.41				
77.295	5						
78.321	42						
83.543	42						
84.794		CrII(30)	0.57				
85.707							
87.280							
88.719							
89.076							
90.415							
90.805							

TABLE 2

Abundances for HD 204411 Compared with Those for Normal A Stars and the Sun

Element	Atomic weight	Number of lines	(8750,4.3,1) v_t = 3.5 km/sec		(8500,4,1) v_t = 4.0 km/sec		Normal A Stars (Conti & Strom 1968)	Sun
			log N/N$_H$ + 12	log N/N$_{Fe}$	log N/N$_H$ + 12	log N/N$_{Fe}$	log N/N$_H$ + 12	log N/N$_H$ + 12
C I	6	ul	7.1	0.0	7.1	-0.3	8.5	
Mg I	12	1	7.8	+0.7	7.6	+0.8	7.4	7.4(WA)
Mg II		4	7.5 ± 0.1	+0.4 ± 0.1	7.2 ± 0.1	+0.4 ± 0.1	7.4	7.4(WA)
Al I	13	ul	3.5	-3.6	3.4	-3.4	5.8	6.1*(WA)
Si II	14	5	7.5 ± 0.3	+0.4 ± 0.3	7.2 ± 0.3	0.4 ± 0.3	7.8	7.6(WA)
Ca I	20	9	6.7 ± 0.1	-0.4 ± 0.3	6.4 ± 0.1	-0.4 ± 0.3		6.3(WA)
Sc II	21	6	2.8 ± 0.1	-4.3 ± 0.1	2.5 ± 0.1	-4.3 ± 0.1	2.8	2.8(CB)
Ti I	22	10	5.6 ± 0.2	-1.5 ± 0.2	5.3 ± 0.2	-1.5 ± 0.2		4.6(CB)
Ti II		50	4.8 ± 0.1	-2.3 ± 0.1	4.5 ± 0.1	-2.3 ± 0.1	4.7	4.5(WA)
V I	23	4	5.1 ± 0.1	-2.0 ± 0.1	4.7 ± 0.3	-2.1 ± 0.3		4.1(CB)
V II		5	4.7 ± 0.8	-2.4 ± 0.8	4.5 ± 0.8	-2.3 ± 0.8	3.5	3.9(WA)
Cr I	24	62	6.2 ± 0.1	-0.9 ± 0.1	6.0 ± 0.1	-0.8 ± 0.1	5.2	5.1(CB)
Cr II		45	6.3 ± 0.1	-0.8 ± 0.1	6.0 ± 0.1	-0.8 ± 0.1	5.5	5.5(WA)
Mn I	25	31	5.5 ± 0.1	-1.6 ± 0.1	5.3 ± 0.1	-1.5 ± 0.1		4.8(CB)
Mn II		2	5.9 ± 0.2	-1.2 ± 0.2	5.8 ± 0.2	-1.0 ± 0.2	5.2	4.9(WA)
Fe I	26	254	7.2 ± 0.1	+0.1 ± 0.1	7.0 ± 0.1	+0.2 ± 0.1	6.6	6.6(CW)
Fe II		38	7.0 ± 0.1	-0.1 ± 0.1	6.8 ± 0.1	-0.2 ± 0.1	6.6	6.5(WA)
Co I	27	1	4.7	-2.4	4.5	-2.3		4.4(CB)
Ni I	28	4	5.5 ± 0.1	-1.6 ± 0.1	5.3 ± 0.1	-1.5 ± 0.1		5.6(CB)
Ni II		4	5.8 ± 0.3	-1.6 ± 0.3	5.6 ± 0.1	-1.5 ± 0.1		5.4(WA)
Zn I	30	ul	2.9	-4.2	2.7	-4.1	3.9	
Sr II	38	3	3.3 ± 0.3	-3.8 ± 0.3	2.9 ± 0.3	-3.9 ± 0.3	3.1	2.8†(WA)
Y II	39	2	2.8 ± 0.2	-4.3 ± 0.2	2.6 ± 0.2	-4.2 ± 0.2	2.7	
Zr II	40	1	3.7	-3.4	3.4	-3.4	3.0	
Ba II	56	1	2.7	-4.4	2.5	-4.3	3.0	
Ce II	58	2	2.8 ± 0.1	-4.3 ± 0.1	2.6 ± 0.1	-4.2 ± 0.1		
Nd II	60	1	1.8	-5.3	1.6	-5.2		
La II			2.5		2.7			
Eu II	63	ul	1.4	-5.7	1.2	-5.6		
Gd II	64	1	3.3	-3.8	3.1	-3.7		
Tm II	69	2	3.5 ± 0.3	-3.6 ± 0.3	3.3	-3.5		

In column 3, ul = upper limit
*From 5944 resonance line
†Does not include 4077 or 4215 in average
CB = Corliss and Bozman (1962)
WA = Warner (1968)