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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 (≤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;

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.

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 $\log g = 4.3 \pm 0.3$. 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 $\tau_\nu = 1$ 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 systematic errors in 1) the model structure, 2) the mechanism of line formation, 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 logarithmic 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 corresponding 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 λ4205 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 λ4130. 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.

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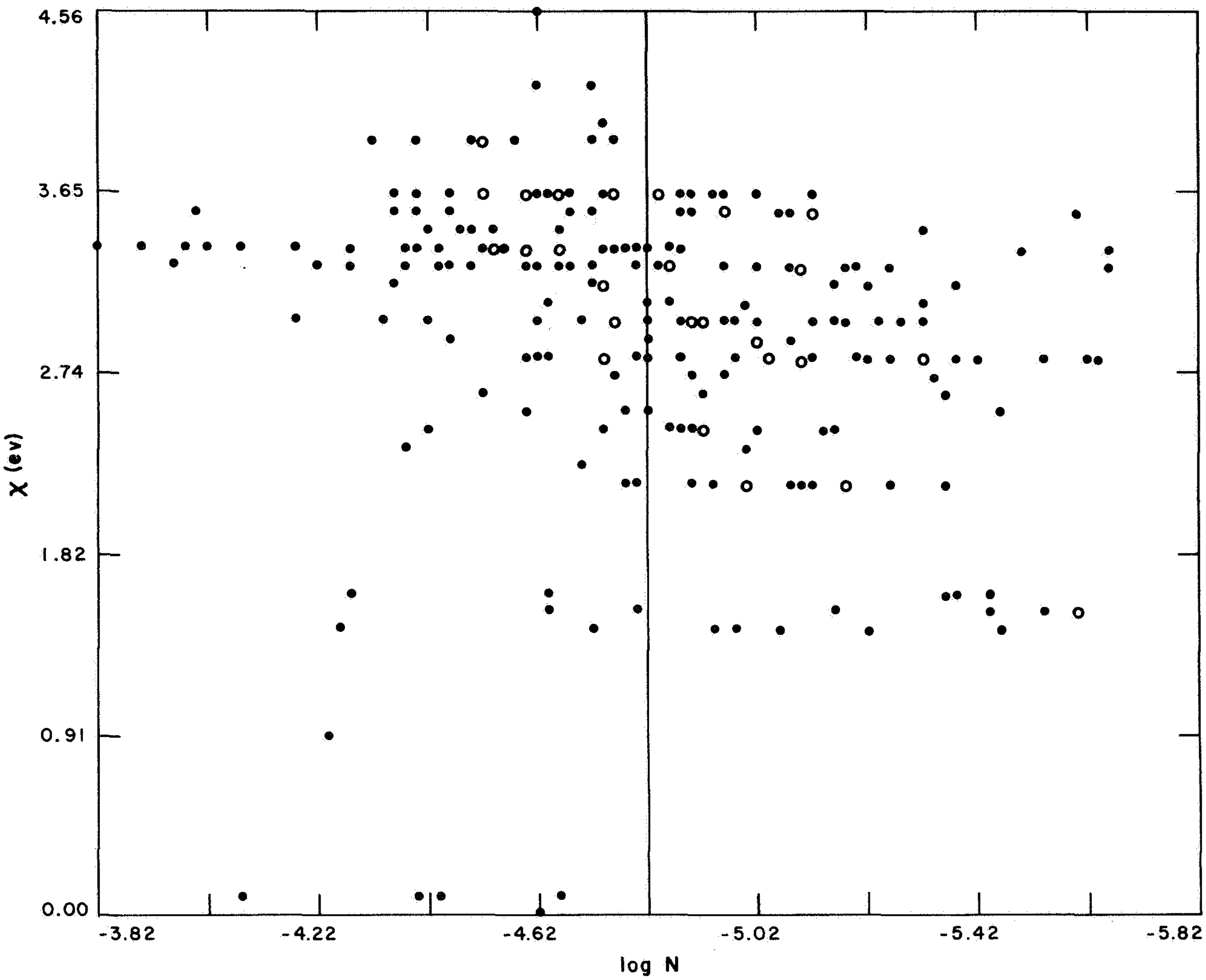


(a)

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.

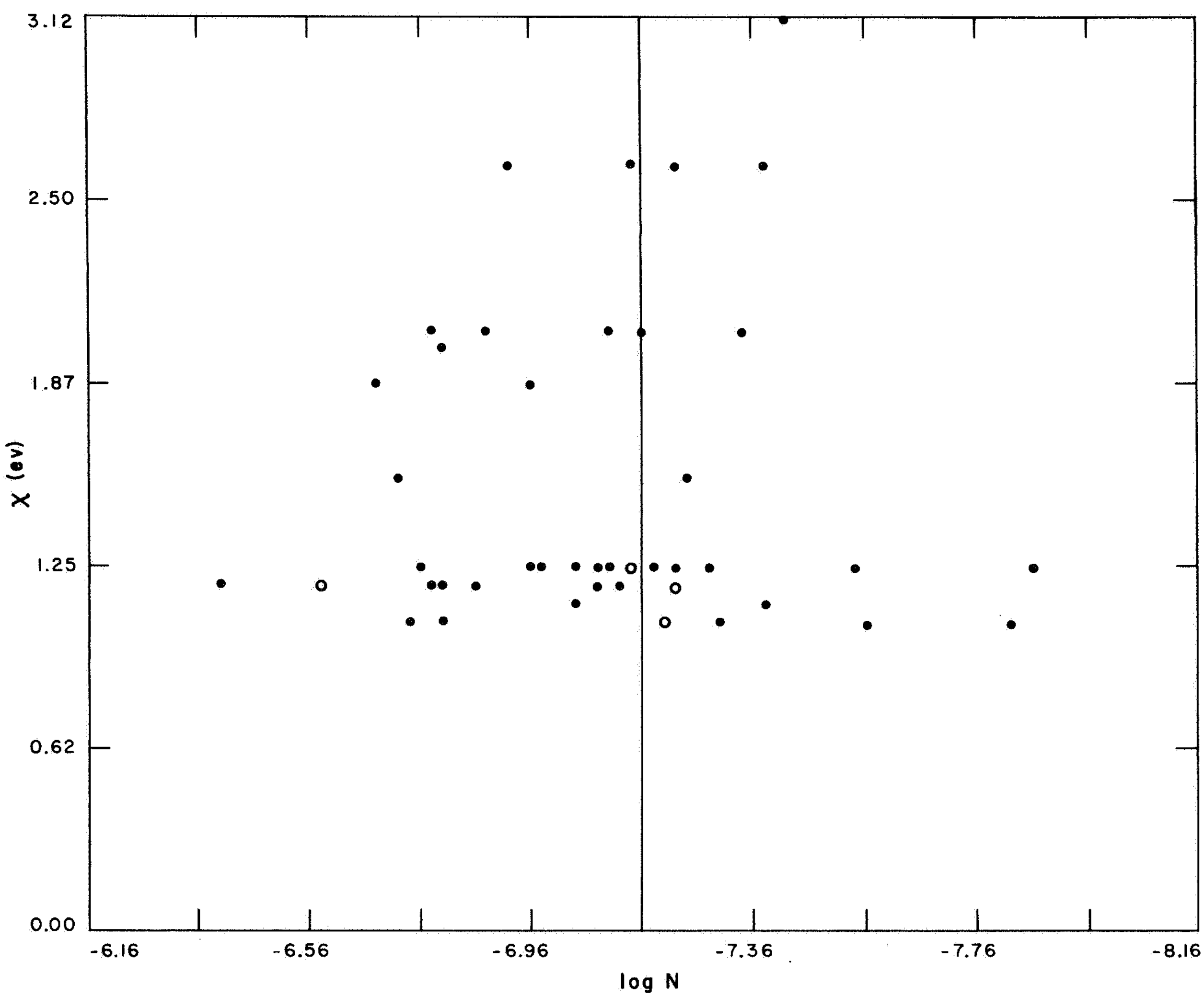


Figure 1. (b)

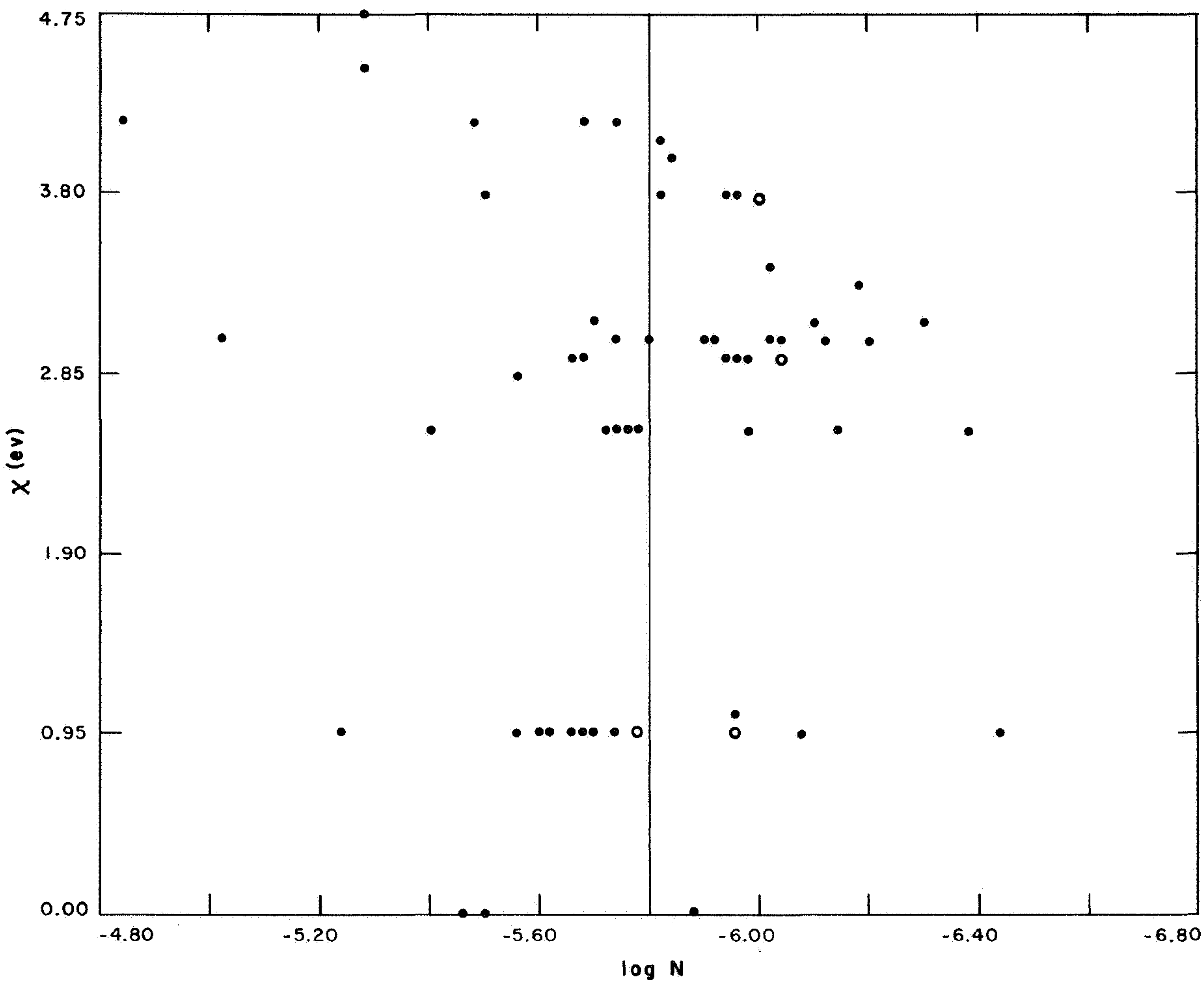
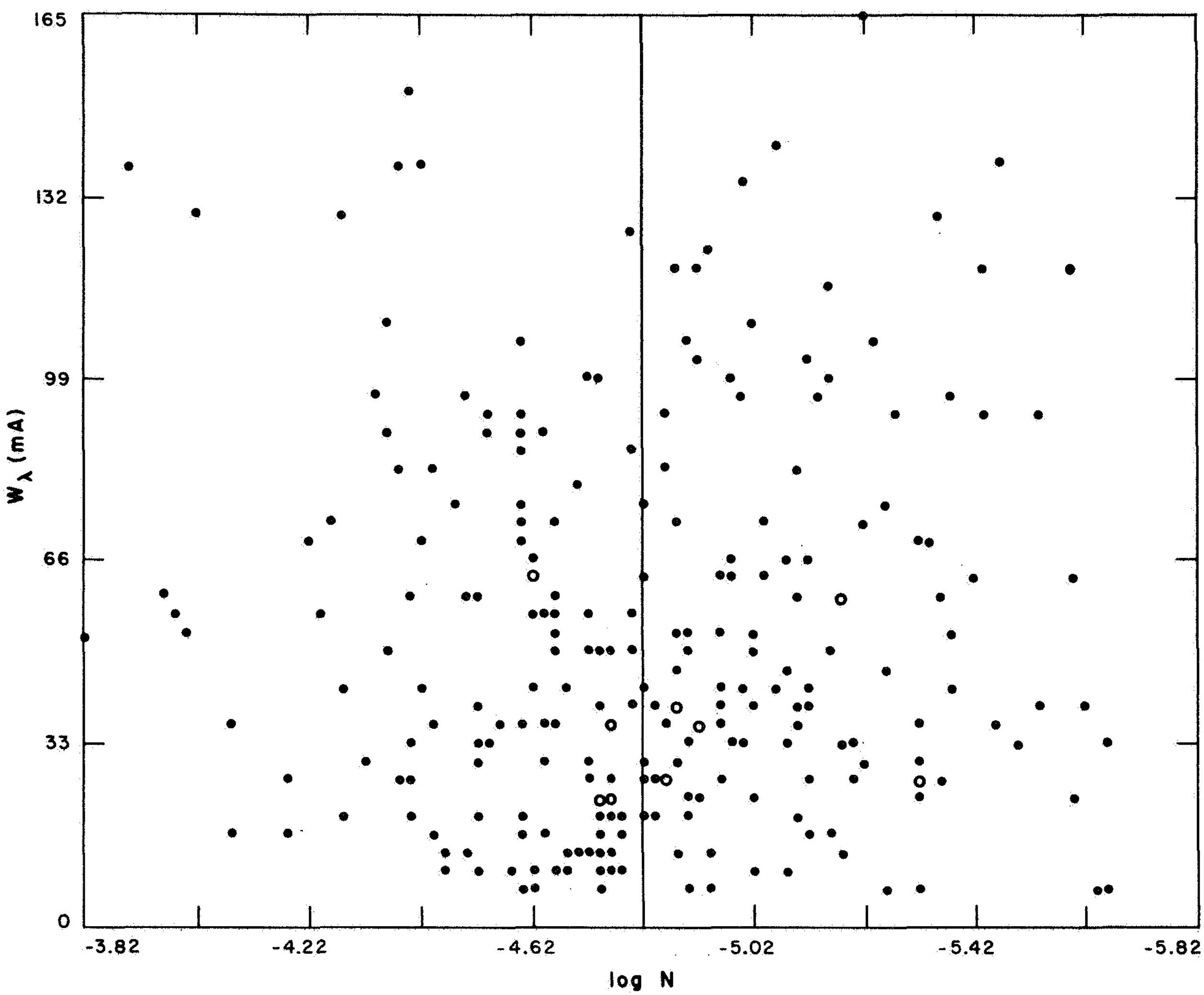


Figure 1. (c)



(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.

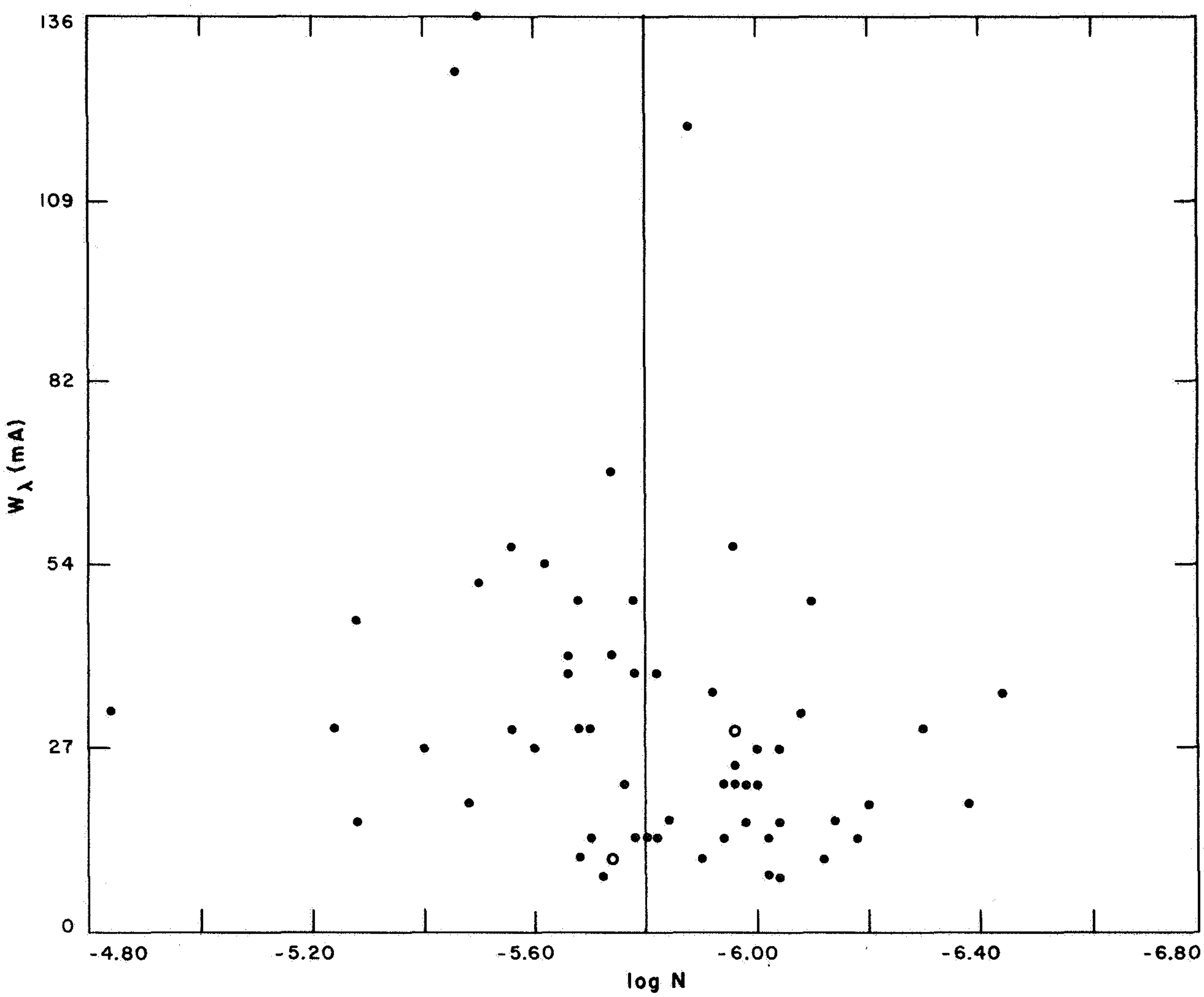


Figure 2. (b)

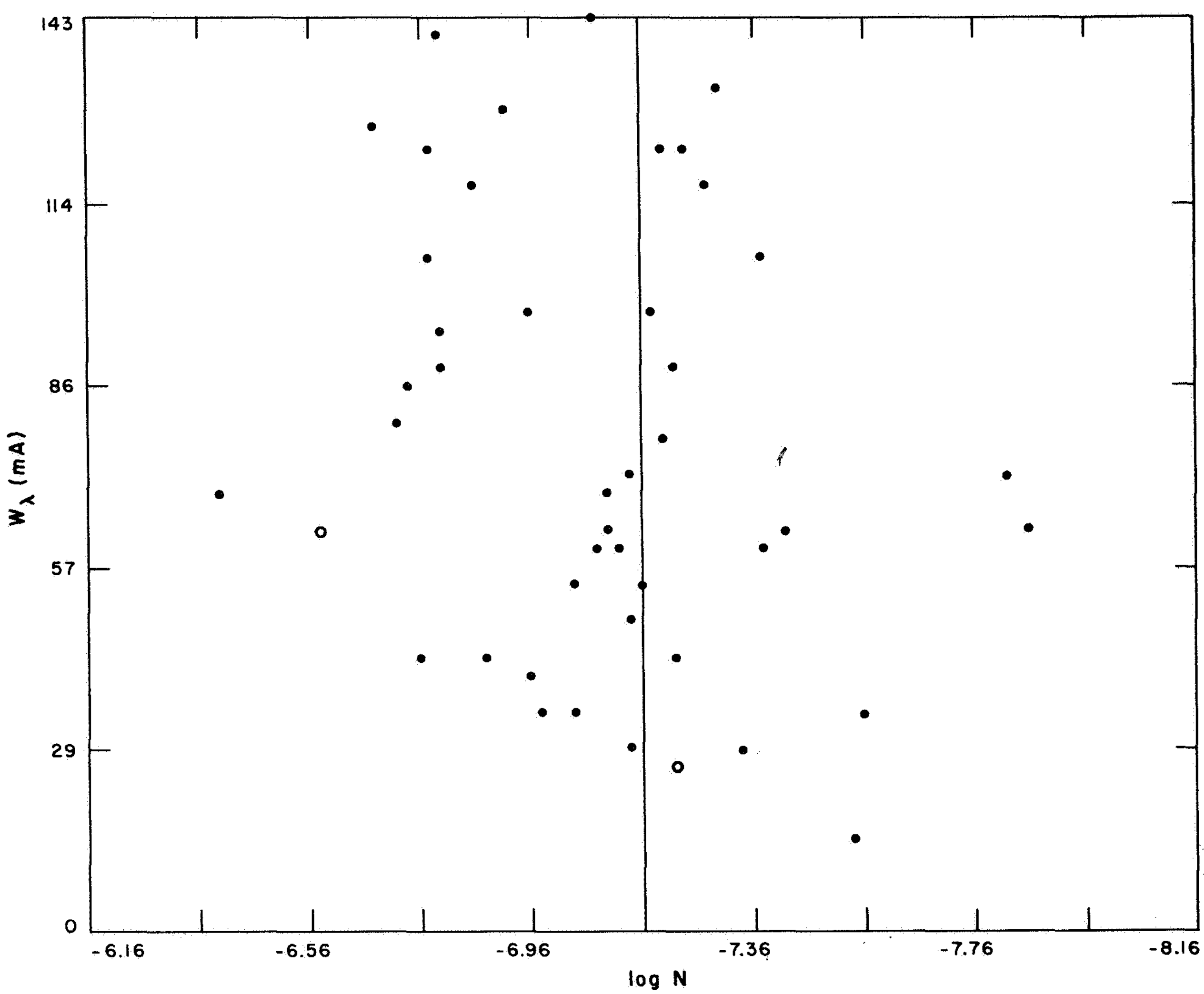
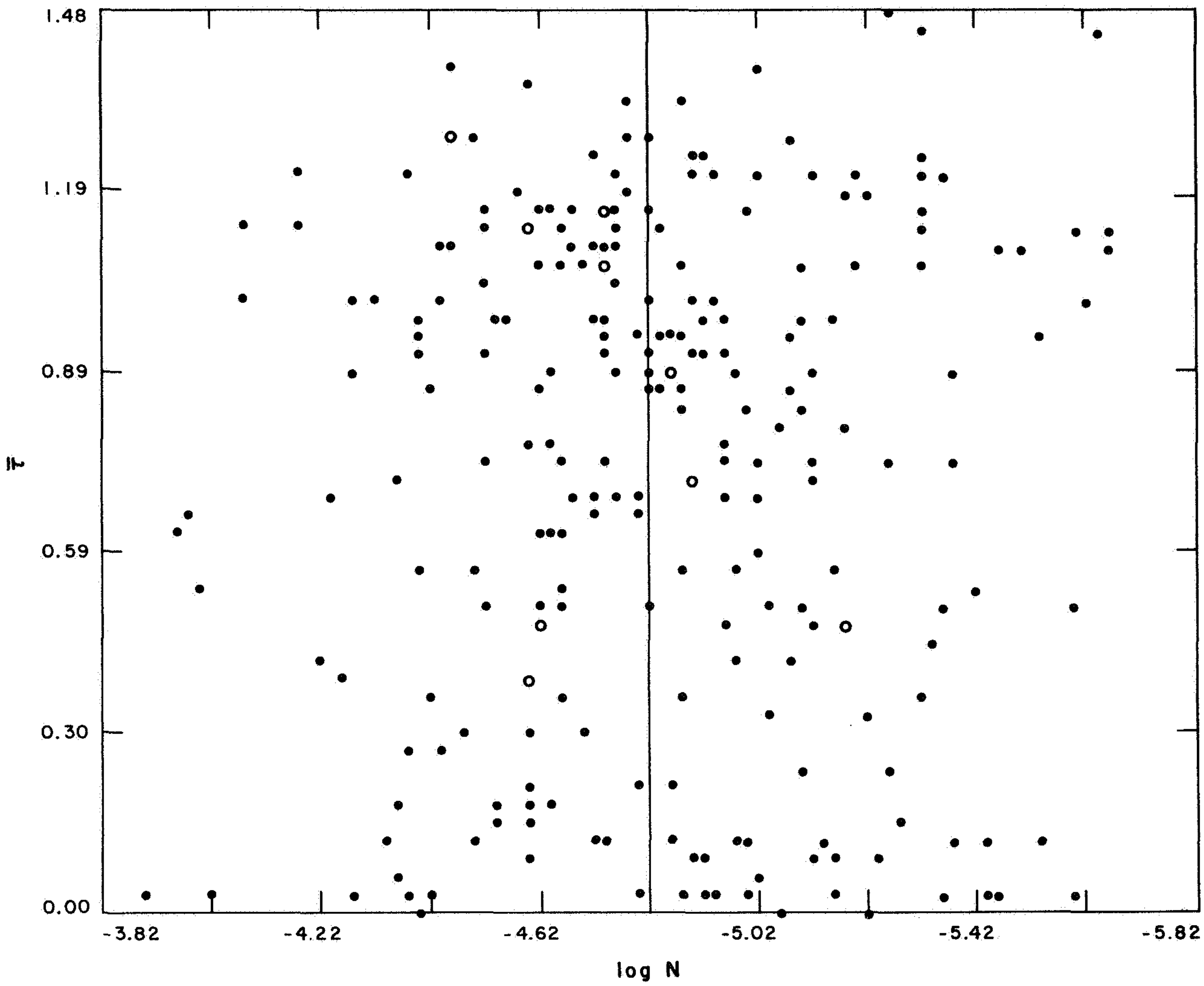


Figure 2. (c)



(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.

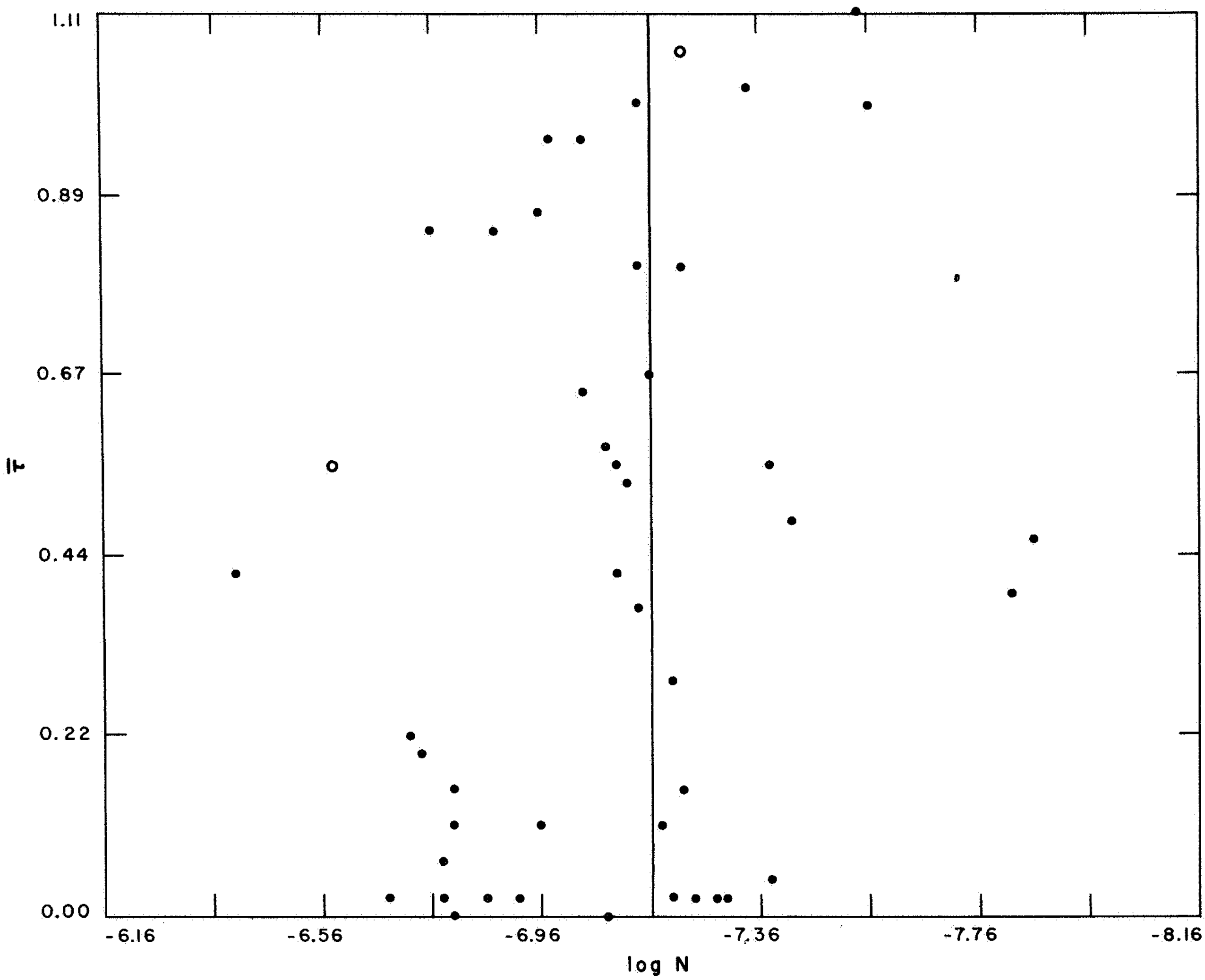


Figure 3. (b)

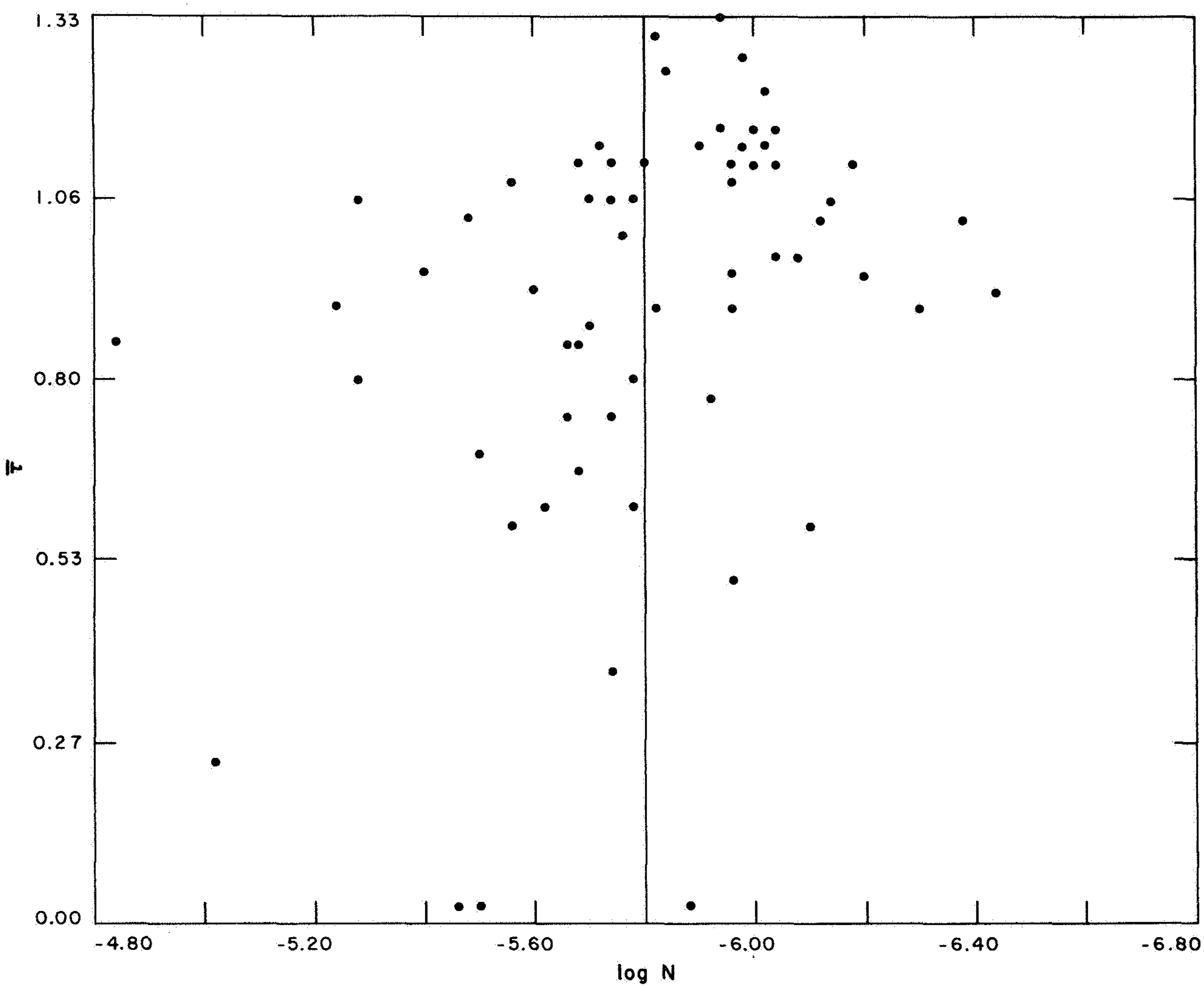


Figure 3. (c)

TABLE 1

Lines Identified as Having Equivalent Widths, W_{λ}, Greater than 5 mÅ

Measured wavelength	W_{λ}(mA)	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
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

Measured wavelength	W_λ(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_λ(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

TABLE 1-Continued

Measured wavelength	W_λ(mA)	Identification	Laboratory wavelength
4027.298	19		
28.362	127	TiII(87)	0.332
28.739	19		
29.668	85	FeI(556, 563)	0.640, TiII(89)
30.444	109	FeI(560)	0.499
30.773	179	MnI(2)	0.775
31.076	19		
31.479	50		
31.706	24		
31.984	65	FeI(655)	0.968
32.462	66		
32.665	71	FeI(44)	0.636
33.034	183	MnI(2)	0.073
34.180	20		
34.495	120	MnI(2)	0.490
35.651	94	MnI(5)	0.728
37.145	23		
37.984	84	CrII(194)	0.03
38.757	58		
39.104	67		
40.083	51		
40.259	9		
40.655	41	FeI(655)	0.650
41.354	109	MnI(5)	0.361
41.637	42		
43.965	94	FeI(276, 557)	0.901
44.575	64	FeI(359)	0.614
45.122	43		
45.616	69	ZrII(30)	0.63
45.824	165	FeI(43)	0.815
46.074	51	FeI(557)	0.07
46.450	9		
46.882	15		
47.490	5		
48.073	10		
48.785	106	MnI(5)	0.755
49.085	70	CrII(193)	0.14
49.337	19	FeI(218)	0.336
50.696	22		
51.228	25		
51.932	112	CrII(19)	0.97
52.436	59	FeI(563)	0.466
52.690	27	FeI(557)	0.72
53.345	39		
53.826	98	TiII(87)	0.814
54.108	95	CrII(19)	0.11
54.551	4		
54.822	82	FeI(698)	0.833
55.058	44	FeI(218)	0.046
55.548	60	MnI(5)	0.543
56.081	54	CrII(182)	0.07
57.514	112	MgI(16)	0.505
57.953	12		
58.225	29	FeI(558)	0.227
58.868	39	MnI(5)	0.930
59.736	24	FeI(767)	0.726
60.656	15		
61.110	19		
61.771	18	CrII(19)	0.77
61.992	20		
62.465	39	FeI(359)	0.446
62.731	12		
63.291	34	FeI(698)	0.286
63.604	119	FeI(43)	0.597
64.071	45	FeI(423)	0.07
64.400	27		
65.035	16		
65.385	8	FeI(698)	0.402
65.710	10		
66.145	19	CrII(182)	0.16
66.623	20		
67.008	100	FeI(358)	0.979
67.273	35	FeI(217)	0.275
67.990	73	MnI(5)	0.103
68.334	5		
68.969	10	TiI(299)	0.981
69.522	10		
69.893	24	FeII(188)	0.883
70.811	89	FeI(558)	0.766
71.494	16	CrII(193)	
		FeI(218)	0.52
71.746	94	FeI(43)	0.740
72.547	67	FeI(195)	0.518
		CrII(26)	0.56
73.771	35	FeI(558)	0.760
74.783	62	FeI(524)	0.794
75.566	12		
75.967	27	FeII(21)	0.95
76.611	52	FeI(558)	0.636
76.857	94	CrII(19)	0.87
77.520	44	CrII(19)	0.50
77.726	115	SrII(1)	0.714
78.375	26	FeI(217)	0.365
79.196	25	MnI(5)	0.241
79.360	25	MnI(5)	0.422
79.853	24	FeI(359)	0.848
80.211	26	FeI(558)	0.226
80.343	5		
80.842	5	FeI(557)	0.886
81.28	10		
82.330	39	CrII(165)	0.30
82.934	10	MnI(5)	0.944
83.664	77	MnII ?	
84.503	33	FeI(698)	0.498
85.000	31	FeI(358)	0.011
85.222	47	FeI(559)	0.312
86.132	42	CrII(26)	0.14
87.174	17		

Measured wavelength	W_λ(mA)	Identification	Laboratory wavelength
4087.32	17		
87.609	30	CrII(19)	0.63
88.818	38	CrII(19)	0.90
89.209	11	FeI(422)	0.225
89.511	30	CrII(164)	0.49
93.01	7		
93.32	7		
97.172	15		
98.573	17		
4101.737			
07.523	13	FeI(352)	0.492
08.433	2		
09.037	3	FeI(558)	0.070
09.550	39		
10.290	2		
10.961	97	(CrII(18))	0.01
		(CrII(26)	0.01
11.590	20		
11.808	22	FeII(21)	0.80
12.594	38	CrII(18)	0.59
12.961	44	FeI(1103)	0.972
13.237	50	CrII(18)	0.24
14.137	5		
14.476	28	FeI(357)	0.449
14.983	14	FeI(695)	0.957
16.984	11	FeI(558)	0.97
17.869	12	FeI(700, 1103)	0.872
18.544	63	FeI(801)	0.549
18.868	44	FeI(559)	0.904
19.527	31	FeII(21)	0.53
20.221	25	FeI(423)	0.211
21.320	28		
21.823	33	FeI(356)	0.806
22.629	92	(FeI(356))	0.552
		(FeII(28))	0.638
23.228	11		
23.775	22	FeI(422)	0.748
24.608	5		
24.77	16	FeII(22)	0.793
25.638	30	FeI(1103)	0.622
25.89	5	FeI(359)	0.884
26.196	41	FeI(695)	0.192
26.523	26		
27.130	36		
27.612	44	FeI(357)	0.612
27.790	41	FeI(558)	0.807
28.116	130	SiII(3)	0.053
28.464	11		
28.749	55	FeII(27)	0.735
29.191	58	CrI(97)	0.21
29.970	17	CrI(97)	0.96
30.899	105	SiII(3)	0.884
31.353	14	CrI(261)	0.360
32.053	95	FeI(43)	0.060
32.473	86	CrII(26)	0.41
32.917	40	FeI(357)	0.903
33.596	10		
33.858	41	FeI(698)	0.869
34.426	23	FeI(482)	0.433
34.679	63	FeI(358)	0.681
35.697	10	ZrI(50)	0.68
36.219	11		
36.517	19	FeI(694)	0.512
36.998	64	FeI(726)	0.002
37.313	15	TiI(253)	0.284
37.400	16		
37.897	5		
38.102	19		
38.349	37		
39.015	9		
39.632	10		
39.805	3		
40.372	22		
41.740	14		
42.187	24	NiI(212)	0.184
42.520	25		
43.451	91	FeI(523)	0.418
43.876	94	FeI(43)	0.871
44.366	5		
45.136	13		
45.766	69	CrII(162)	0.77
46.049	28	FeI(422)	0.071
46.375	33		
46.961	26		
47.331	28	FeI(693)	0.34
47.666	57	FeI(42)	0.673
48.255	5	FeI(832p)	0.27
49.381	72	FeI(694)	0.372
50.231	44	FeI(695)	0.258
50.563	16	TiI(253)	0.557
50.995	54	CrII(163)	0.00
52.080	80		
53.874	105	FeI(695)	0.906
54.121	37	FeI(694)	0.109
54.487	83	FeI(355)	0.502
54.791	86	FeI(694)	0.812
55.279	3		
55.977	11		
56.330	69		
56.771	74	FeI(354)	0.803
57.778	77	FeI(695)	0.788
58.257	15		
58.772	75	FeI(695)	0.798
59.140	87		
60.323	41		
60.645	34	FeI(689)	0.625
61.082	55	FeI(689)	0.080

TABLE 1-Continued

Measured wavelength	W_λ(mA)	Identification	Laboratory wavelength
4161.463	86	TiII(21)	0.524
61.807	29	SrII(3)	0.796
63.633	132	TiII(105)	0.644
65.38	33		
65.494	46	CrI(305)	0.519
67.281	95	MgI(15)	0.27
67.921	36	FeI(599)	0.862
68.665	53	FeI(689)	0.625
68.955	17	FeI(694)	0.942
69.799	36	FeI(693)	0.777
70.158	13	CrI(278)	0.202
70.626	49	CrII(18)	0.58
70.972	95	FeI(482)	0.906
71.661	46	FeI(941)	0.696
71.925	130	TiII(105)	0.897
72.114	96	FeI(649)	0.126
72.692	105	FeI(689)	0.641
73.493	171	FeII(27)	0.450
74.096	50	TiII(105)	0.088
74.350	61	MnII?	
74.874	56	FeI(19)	0.917
75.23	7		
75.631	73	FeI(354)	0.640
76.067	26		
76.577	89	FeI(695)	0.571
77.651	112	FeI(18)	0.597
78.075	34		
78.511	10		
78.857	136	FeII(28)	0.855
79.379	149	CrII(26)	0.43
80.47	9		
80.98	13		
81.744	102	FeI(354)	0.758
81.999	77		
82.385	52	FeI(476)	0.384
82.732	33	FeI(694)	0.790
83.153	10	FeII(21)	0.20
83.317	10		
83.493	16	VII(37)	0.435
83.989	87		
84.334	76		
84.887	73	FeI(335)	0.895
87.046	97	FeI(152)	0.044
87.588	49	FeI(694)	0.59
87.823	139	FeI(152)	0.802
88.747	96		
89.533	19	FeI(940)	0.564
90.131	29	CrI(84)	0.16
91.416	103	FeI(152)	0.436
91.694	64	FeI(355)	0.685
92.061	30	NiII(10)	0.07
93.652	22	CrI(248)	0.662
95.066	18		
95.354	129	FeI(693)	0.337
95.624	31	FeI(478)	0.615
96.209	72	FeI(693)	0.218
96.481	16		
97.171	19		
98.068	75		
98.292	139	FeI(152)	0.310
98.647	70	FeI(693)	0.645
99.092	106	FeI(522)	0.098
99.474	33		
99.851	30		
4200.021	10	FeI(993)	0.09
4200.557	24		
4200.931	61	FeI(689)	0.930
01.440	5		
02.031	122	FeI(52)	0.031
02.559	40		
02.746	30	FeI(476a, 521)	0.755
03.580	15	CrI(35)	0.590
03.963	88	FeI(355)	0.987
04.46	16	CrI(272)	0.471
05.096	30	VII(37)	0.080
05.33	88		
05.480	66	(FeI(089))	0.546
		(FeII(22))	0.48
06.282	27		
06.54	51		
06.785	16		
07.131	50	FeI(352)	0.130
07.391	82	CrII(26)	0.35
07.85	14		
08.633	62	FeI(689)	0.610
09.077	42	CrII(162)	0.02
09.36	27	CrI(248)	0.368
09.606	23		
09.798	50		
10.364	98	FeI(152)	0.352
11.002	16		
11.27	7		
11.76	10		
12.60	2		
13.14	6		
13.610	55	FeI(355)	0.650
15.501	162	SrII(1)	0.525
15.760	68	CrII(18)	0.77
16.273	43	FeI(3)	0.186
		CrI(132)	0.315
17.065	57	CrII(18)	0.07
17.556	92	FeI(693)	0.551
17.841	10		
18.145	16		
19.394	100	FeI(800)	0.364
20.061	61		
20.359	42	FeI(482)	0.347
21.984	35	CrII(180)	0.00

Measured wavelength	W_λ(mA)	Identification	Laboratory wavelength
4222.202	83	FeI(152)	0.219
24.156	92	FeI(689)	0.176
24.514	59	FeI(689)	0.509
24.837	89	CrII(162)	0.85
25.458	71	FeI(693)	0.460
25.70	30		
25.943	36	FeI(521)	0.956
26.390	44	FeI(352)	0.426
26.714	153	CrI(2)	0.728
27.385	153	FeI(693)	0.434
29.446	29	FeI(416, 649)	0.516
29.790	40	FeI(41)	0.760
30.449	13	CrI(132)	0.481
30.937	2.		
31.842	28		
33.171	210	FeII(27)	0.167
33.598	105	FeI(152)	0.608
35.304	32	MnI(23)	0.290
35.914	120	FeI(152)	0.942
36.365	50	CrII(12)	0.33
37.266	25		
37.987	65	FeI(689)	0.027
38.800	129	FeI(693)	0.816
38.84	16		
39.02	16		
39.809	61	FeI(273)	0.847
			Blend
40.374	51	FeI(764)	0.372
40.667	22	CrI(105)	0.705
41.032	8		
41.470	8.		
42.371	140	CrII(31)	0.38
42.675	29		
43.412	10		
43.704	12		
44.224	12	MnII(7)	0.26
44.817	12	NiII(9)	0.80
45.302	76	FeI(352)	0.258
46.044	17	FeI(906)	0.090
46.386	49	CrII(31)	0.41
46.846	80	SiII(7)	0.829
47.421	94	FeI(693)	0.432
48.232	56	FeI(482)	0.228
50.135	109	FeI(152)	0.125
50.438	38		
50.804	125	FeI(42)	0.790
51.726	23	GdII(15)	0.733?MnII? 0.70
52.20	10	CrI(131)	0.243
52.631	99	CrII(31)	0.62
53.010	32	MnII(7)	0.02
54.341	120	CrI(1)	0.346
54.52	81		
55.495	23	CrI(105)	0.502
56.132	42	CrII(192)	0.16
56.67	7	CrI(131)	0.620
57.35	9	CrI(131)	0.368
57.59	9		
58.133	84	FeII(28)	0.155
58.337	54	FeI(3)	0.320
58.719	13		
59.04	11	FeI(419)	0.956
59.258	53		
60.069	66		
60.476	136	FeI(152)	0.479
61.266	19		
61.914	154	CrII(31)	0.92
62.289	9		
62.716	5		
63.143	38	CrI(247)	0.141
63.861	32		
64.201	34	FeI(692)	0.209
64.756	12	FeI(993)	0.743
65.269	31	FeI(993)	0.260
66.037	13		
66.967	32	FeI(273)	0.968
67.815	43	FeI(482)	0.830
68.837	42	CrI(271)	0.788
69.278	96	CrII(31)	0.28
71.151	118	FeI(152)	0.159
71.779	143	FeI(42)	0.764
73.304	86	FeII(27)	0.317
74.798	136	CrI(1)	0.803
75.570	119	CrII(31)	0.57
75.978	21	CrI(240)	0.973
76.673	21	FeI(976)	0.684
77.567	15		
78.163	85		
78.637	7		
79.011	6		
79.482	12	FeI(993)	0.480
79.888	4	ScII(15)	0.927
80.384	51	CrI(247)	0.405
81.060	31	CrII(17)	0.03
81.905	4		
82.436	96	FeI(71)	0.406
83.007	87	CaI(5)	0.010
83.756	19	MnII(6)	0.772
84.206	102	CrII(31)	0.21
84.42	15	FeI(417)	0.415
84.916	6		
85.424	51	FeI(597)	0.445
85.862	5	FeI(904)	0.832
86.287	8	FeII(n)	0.311
86.45	11	FeI(414)	0.440
86.988	33	FeI(976)	0.976
87.874	94	TiII(20)	0.893
88.121	26	FeI(273)	0.148
89.060	7		

TABLE 1-Continued

Measured wavelength	W_λ(mA)	Identification	Laboratory wavelength
4289.369	81	CaI(5)	0.364
89.702	127	CrI(1)	0.721
90.259	140	TiII(41)	0.222
90.951	15	TiI(44)	0.433
91.504	14	FeI(41)	0.466
91.97	14	CrI(240)	0.964
92.244	46	(FeI(70p))	0.13
		(FeI(70))	0.293
93.059	5		
93.543	6	CrI(96)	0.565
94.096	163	FeI(41)	0.128
		TiII(20)	0.101
94.722	5	ScII(15)	0.767
95.288	9		
95.785	27		
96.575	92	FeII(28)	0.567
97.074	2		
97.740	22	CrI(247)	0.738
98.038	37	FeI(520)	0.040
98.651	2	TiI(44)	0.664
98.991	67	CaI(5)	0.986
99.251	98	FeI(152)	0.242
99.631	22		
4300.050	143	TiII(41)	0.052
4300.496	22	TiI(44)	0.566
01.184	27		
01.947	116	TiII(41)	0.928
02.292	30	FeI(42)	0.031
		FeI(520)	0.191
02.527	97	CaI(5)	0.527
03.178	121	FeII(27)	0.166
03.572	5	NdII(10)	0.573
04.162	7	VII(213)??	
04.504	10	FeI(414)	0.552
05.20	9	FeI(760)	0.20
05.451	64	FeI(476)	0.455
05.803	17	ScII(15)	0.715
06.911	57		
07.834	170	CaI(5)	0.741
		TiII(41)	0.900
		FeI(42)	0.906
09.062	40	FeI(849)	0.036
09.395	51	FeI(414)	0.382
09.710	33		
10.048	1		
10.457	11		
12.444	5	CrI(177)	0.469
12.888	124	TiII(41)	0.861
13.765	5		
14.086	41	ScII(15)	0.084
14.307	76	FeII(32)	0.289
15.025	165	TiII(41)	0.979
15.450	8	FeI(71)	0.087
16.809	62	TiII(94)	0.807
17.942	5		
18.152	14		
18.677	71	CaI(5)	0.652
19.443	17		
19.691	45	FeII(220)	0.717
20.749	54	ScII(14)	0.745
20.964	70	TiII(41)	0.965
21.34	21	FeII(220)	0.341
21.77	14		
25.033	68	CnI(104)	0.075
		ScII(15)	0.010
25.464	58		
25.787	128	FeI(42)	0.765
26.688	70		
27.115	33	FeI(761)	0.100
30.266	44	TiII(94)	0.264
30.728	63	TiII(41)	0.708
37.112	22	FeI(41)	0.049
37.503	33	CrI(22)	0.566
37.927	71	TiII(20)	0.916
40.522	89	H	
44.002	54	MnII(6)	0.987
44.295	34	TiII(20)	0.291
44.518	36	CrI(22)	0.507
46.592	20	FeI(598)	0.558
46.851	39	CrI(104)	0.833
47.375	5		
47.770	19		
48.343	32		
50.861	30	TiII(94)	0.834
51.068	24	CrI(22)	0.051
51.558	14	FeI(413)	0.549
51.869	178	FeII(27)	0.764
52.707	73	FeI(71)	0.737
53.262	1		
54.314	25	FeII(213)	0.358
55.091	37	CaI(37)	0.096
57.586	36	FeII(u)	0.574
58.493	30	FeI(412)	0.505
59.642	55	CrI(22)	0.631
60.754	13		
61.270	27	FeII(u)	0.249
62.083	25	NiII(9)	0.10
62.423	16		
62.932	46	CrII(179)	0.93
66.107	15		
67.641	118	FeI(414)	0.581
		TiII(104)	0.657
67.934	17	FeI(41)	0.906
68.138	61		
68.533	6		
68.904	5	TiI(245)	0.941
69.422	56	FeII(28)	0.404
69.799	62	FeI(518)	0.774
71.060	17		
71.310	57	CrI(22)	0.279

Measured wavelength	W_λ(mA)	Identification	Laboratory wavelength
4373.564	36	FeI(214, 413)	0.563
74.158	31	CrI(104)	0.158
74.490	50	ScII(14)	0.455
74.890	89	TiII(93)	0.825
75.361	25	TiII(104)	0.35
75.931	55	FeI(2)	0.932
76.776	32	FeI(471, 904)	0.782
77.441	14		
77.835	4		
78.536	5		
79.064	5		
79.827	7		
80.589	7		
80.859	13		
81.240	13		
81.843	5		
82.471	12		
82.692	32		
83.534	137	FeI(41)	0.547
83.961	25		
84.303	70		
84.693	35	MgII(10)	0.643
84.980	35	CrI(22)	0.477
85.373	99	FeII(27)	0.373
85.693	5		
86.184	3		
86.582	10		
86.841	61	TiII(104)	0.858
87.434	10		
87.892	36	FeI(476)	0.897
88.393	42	FeI(830)	0.412
89.313	2		
90.130	5		
90.550	33	MgII(10)	0.585
90.992	69	FeI(414)	0.954
91.780	41		
92.58	14		
93.277	15		
94.055	72	TiII(51)	0.057
95.011	131	TiII(19)	0.031
95.46	13		
95.825	70	TiII(61)	0.848
97.352	4		
97.91	9		
98.274	25	TiII(61)	0.314
99.759	97	TiII(51)	0.767
4400.374	25	ScII(14)	0.355
4400.620	11	TiII(93)	0.63
4400.940	20		
01.272	38	FeI(828)	0.293
01.476	22	FeI(350)	0.447
02.907	35	FeII(u)	0.875
03.116	17		
03.473	28		
04.743	119	FeI(41)	0.742
06.74	12		
07.699	72	(TiII(51))	0.678
		(FeI(68))	0.714
08.405	49	FeI(68)	0.419
08.74	2		
09.197	30	TiII(61)	0.22
09.539	41	TiII(61)	0.519
10.162	8		
11.044	64	TiII(115)	0.080
11.35	1		
11.963	34	TiII(61)	0.936
12.185	6	CrI(22)	0.250
12.470	5	FeI(69)	0.43
13.573	43	FeII(32)	0.600
13.743	13		
14.776	22	MnI(22)	0.879
15.120	94	FeI(41)	0.125
15.545	20	ScII(14)	0.559
15.965	2		
16.820	100	FeII(27)	0.817
17.724	90	TiII(40)	0.718
18.343	60	TiII(51)	0.340
18.916	25	GdII(15)	0.032
21.957	53	TiII(93)	0.941
22.473	65	FeI(350)	0.570
22.947	22	FeI(646)	0.882
23.288	42	TiII(61)	0,22
23.873	15	FeI(830)	0.858
24.273	16	CrI(129)	0.281
25.429	60	CaI(4)	0.441
27.313	54	FeI(2)	0.312
27.909	15	TiII(61)	0.90
28.475	11	VI(921)	0.515
29.237	5	CeII(19)	0.270
30.076	32		
30.511	50	FeI(68)	0.618
31.641	15	FeII(222)	0.626
31.806	19		
32.153	34	TiII(51)	0.089
32.661	14		
33.227	49	FeI(830)	0.223
33.758	27	FeI(825)	0.793
34.028	22	TiI(113)	0.003
34.977	71	CaI(4)	0.960
35.23	16	FeI(2)	0.151
35.691	57	CaI(4)	0.688
36.087	6	VI(21)	0.087
36.407	6	MnI(22)	0.352
36.918	8	FeI(516)	0.931
37.828	5	VI(21)	0.837
38.364	12	FeI(828)	0.353
40.460	15	FeI(829)	0.479
40.829	9	FeI(992)	0.840

TABLE 1-Continued

Measured wavelength	W_λ(mA)	Identification	Laboratory wavelength
4441.124	12		
41.751	45	TiII(40)	0.73
42.364	60	FeI(68)	0.343
42.83	8	FeI(69)	0.835
43.188	45	FeI(350)	0.197
43.77	122	TiII(19)	0.802
44.320	11	CeII(19)	0.393
44.541	55	TiII(31)	0.559
45.183	8		
46.255	25	FeII(187)	0.248
46.860	23	FeI(828)	0.842
47.130	11	FeI(69)	0.134
47.742	60	FeI(68)	0.722
48.6	2		
49.624	22	FeII(222)	0.663
50.494	78	TiII(19)	0.487
50.9	2		
51.567	57	MnI(22)	0.586
		FeII(n)	0.545
51.996	2	VI(87)	0.008
52.7	2		
53.0	2	MnI(22)	0.005
53.286	16	TiI(113)	0.312
54.378	38	FeI(350)	0.383
54.763	82	CaI(4)	0.781
54.989	27	(FeI(474))	0.135
		(MnI(28))	0.012
55.273	48	MnI(28)	0.318
55.881	58	(MnI(28))	0.821
		(CaI(4))	0.887
56.425	7		
56.638	34	CaI(4)	0.612
57.0	7	MnI(28)	0.045
57.466	19	MnI(28)	0.549
58.100	22	MnI(28)	0.262
58.537	26	CrI(127)	0.538
59.090	61	FeI(68)	0.121
59.322	33		
59.7	14	CrI(127)	0.738
61.155	17	MnI(28)	0.085
61.423	43		
61.682	58	FeI(2)	0.654
61.991	52	MnI(28)62	0.022
62.385	1	VI(87)	0.363
63.342	10		
64.443	61	TiII(40)	0.458
64.609	33	CrI(127)	0.669
65.072	11	CrI(1127)	4.909
65.339	11	CrI(127)	0.357
65.727	26	CrII(191)	0.78
66.561	70	FeI(350)	0.554
66.828	11	FeI(992)	0.939
67.9	7		
68.490	27	TiII(31)	0.493
69.195	33		
69.395	53	FeI(830)	0.381
70.495	11		
70.860	44	TiII(40)	0.864
71.234	17		
72.937	55	FeII(37)	0.921
74.261	19	FeII(171)	0.194
74.556	9		
79.8	2	TiI(113)	0.852
75.343	9		
76.066	88	FeI(830)	0.082
		FeI(350)	0.021
78.651	13	GdII(15)	0.795
79.340	2		
79.637	19	FeI(828)	0.612
80.236	21	CrI(197)	0.263
80.730	30		
81.127	177	MgII(4)	0.129
81.334	174	MgII(4)	0.327
81.662	28		
82.230	65	FeI(68)	0.257
82.773	24	CrI(197)	0.878
84.228	43	FeI(828)	0.227
85.678	28	FeI(830)	0.679
87.523	22		
88.333	21	TiII(115)	0.319
88.441	70		
89.172	100	FeII(37)	0.185
89.480	20		
89.811	16	FeI(2)	0.741
90.082	29	MnI(22)	0.081
90.751	30	FeI(974)	0.773
91.408	86	FeII(37)	0.401
91.824	2		
92.311	13	CrI(197)	0.312
92.742	10	FeI(964)	0.693
93.535	39	FeII(222)	0.579
94.025	15		
94.586	59	FeI(68)	0.568
95.441	7	FeI(314, 470)	0.386
95.908	11		
96.252	2		
96.878	50	CrI(10)	0.862
98.737	13	MnI(22)	0.897
99.304	21		
99.668	17		
4500.386	80	CrI(150)	0.295
01.297	106	TiII(31)	0.270
01.763	12	CrI(81)	0.788
02.304	10	MnI(22)	0.220
02.746	3		
03.065	5		
03.535	1		
03.735	2	TiI(184)	0.762

Measured wavelength	W_λ(mA)	Identification	Laboratory wavelength
4503.935	2		
04.421	6		
04.558	16		
04.74	9		
06.859	19	CrI(288)	0.853
07.161	32		
08.268	105	FeII(38)	0.283
09.727	16		
10.545	11		
11.813	36		
13.245	6		
14.128	14	FeI(514)	0.189
14.429	34	CrI(287)	0.373
15.319	103	FeII(37)	0.337
15.553	33	CrI(126)	0.440
15.825	24		
16.639	14		
17.150	10		
17.499	18		
17.96	5		
18.314	29		
20.212	93	FeII(37)	0.225
21.099	11	CrI(287)	0.141
22.629	115	FeII(38)	0.634
23.414	13	FeI(829)	0.403
24.749	14	TiII(60)	0.732
25.148	54	FeI(826)	0.142
26.092	7	CrI(196)	0.108
26.443	68	CrI(33)	0.466
26.910	25		
27.360	22	CrI(33)	0.339
28.621	77	FeI(628)	0.619
29.502	81	TiII(82)	0.465
30.704	40	CrI(33)	0.688
			0.755
31.133	34	FeI(39)	0.152
31.750	13	FeI(555)	0.663
32.999	30	CrI(212)	0.75
33.235	23	TiI(42)	0.238
33.974	116	TiII(50)	0.966
34.172	68	FeII(37)	0.166
34.780	12	TiI(42)	0.782
35.118	14	CrI(33)	0.146
35.680	43	TiI(42)	0.574
36.250	5		
38.575	15		
39.577	60	CrII(39)	0.62
39.748	27	CrI(33)	0.788
40.535	30	CrI(33)	0.502
40.749	34	CrI(150)	0.719
40.071	18	CrI(33)	0.071
41.497	68	FeII(38)	0.523
42.520	11	FeI(894)	0.422
42.820	7	CrI(19)	0.621
43.044	28		
44.628	40	CrI(33)	0.619
45.138	40		
45.525	9	CrI(33)	0.335
45.953	34	CrI(10)	0.895
46.666	10		
46.076	10	FeI(39)	0.022
47.864	37		
49.193	53	FeII(186)	0.214
49.551	153	FeII(38)	0.467
49.830	55	TiII(82)	0.622
50.791	43		
52.288	28		
52.483	14	TiI(42)	0.453
53.028	78	BaII(1)	0.033
54.013	95	CrII(44)	0.02
55.887	102	FeII(37)	0.890
56.139	56	FeI(820)	0.129
57.285	14		
58.13	5	FeI(894)	0.108
58.676	141	CrII(44)	0.659
59.532	0		
60.099	9	FeI(823)	0.096
61.193	5		
61.499	10	CrI(277)	0.54
62.53	3		
63.23	7	CrI(296)	0.245
63.789	64	TiII(50)	0.761
64.127	15	CrI(312)	0.166
64.585	30		
65.584	31	CrI(21)	0.512
65.740	91	CrII(39)	0.78
66.539	10	FeI(841)	0.520
66.924	22		
68.275	22		
68.782	7	FeI(554)	0.789
69.200	2		
69.602	17	CrI(173)	0.530
			0.644
71.194	22	CrI(125)	0.105
71.676	16	CrI(32)	0.671
71.992	124	TiII(82)	0.971
72.503	5		
72.817	5		
73.621	5		
74.278	5	FeI(554)	0.240
75.178	2		
75.786	5		
76.356	74	FeII(38)	0.331
77.070	5		
77.43	5		
77.970	8		
78.576	30	CaI(23)	0.558
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	TiI(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)	0.628
		FeI(821)	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
4745.811	20	FeI(821)	0.806
48.160	53		
49.846	12		
54.077	26		
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			
4891.564			
92.992			
93.337			
93.839			

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 log N/N_H + 12	log N/N_{Fe}	(8500, 4, 1) v_t = 4.0 km/sec log N/N_H + 12	log N/N_{Fe}	Normal A Stars (Conti & Strom 1968) log N/N_H + 12	Sun 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)