

THE SPECTRUM OF PLEIONE*

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ABSTRACT

The radial velocity of Pleione shows oscillations with a range of 10 km/sec and a period of about four months. The mean velocity is +5.5 km/sec. The spectrum of the shell, first discovered by McLaughlin and Mohler in 1938, has gradually become stronger and now resembles the metallic spectrum of α Cygni. Dilution effects are conspicuous in the weakness of Mg II and Si II. Among the lines of ions having metastable lower levels, Ni II and Fe II became conspicuous in 1940, Ti II in 1941, and Mn II in 1942. This order of development is not consistent with the ordinary theory of ionization, and its explanation must be sought in the conditions of excitation of the metastable levels in the shell. The central intensities of the cores of the H lines are about 10 per cent—roughly one-half or one-third of the central intensities of the corresponding lines in α Cygni. This is explained as a consequence of the reduced re-emission which is thrown back within the shell into the emerging beam of radiation from the star. The metallic lines on the violet side of the Balmer limit and between the higher members of the series are relatively much stronger than in α Cygni. This is due to the semitransparency of the shell, on the one hand, and to the absence of Stark effect wings in the shell, on the other.

1. Since 1938 the spectrum of Pleione (BS 1180 = 28 Tauri; $\alpha = 3^h43^m2$, $\delta = +23^\circ50'$ [1900]) has shown double bright lines at $H\alpha$ and $H\beta$ and a set of strong, sharp absorption lines resembling the lines of α Cygni.¹ The lines of Mg II and Si II are conspicuously weak and broad, suggesting that the sharp-line absorption takes place in a layer in which the exciting radiation of the star is diluted by a factor of the order of $W = 0.1$. The very broad He I lines of the original star are not now visible, and this may in part be due to continuous absorption within the shell. The violet component of the double emission line at $H\beta$ is somewhat stronger than the red, but on some recent plates the difference is less noticeable than on plates taken in 1938 and 1940.

2. Several stars with shell spectra are known to have variable radial velocities (ϕ Per, ζ Tau, 17 Lep, 48 Lib). Table 1 gives the velocities measured on 76 spectrograms of Pleione taken at the Yerkes and McDonald Observatories. There are conspicuous fluctuations with a range of about 10 km/sec and a period of about four months. Some of the plates taken in 1941–42 were not intended for accurate determinations of radial velocities, and the observed scatter is large. In 1942–43 the scatter is much less, and the curve is very clearly defined. In Figures 1 and 3 the velocities are plotted separately for each date. Average values are plotted when there were two or more plates during the same night. Figures 2 and 4 show the smoothed curves, obtained by taking running means of three successive velocities, as listed in Table 1.

Two well-defined minima were observed: JD 2430260 and JD 2430685. The difference of 425 days suggests periods of either 106 days or 142 days. The latter value is the more probable one, but the shapes of the two curves are not very similar, and it is possible that the fluctuations in velocity are somewhat irregular. It is interesting that the value $P = 142$ days is similar to the periods of ϕ Per, ζ Tau, and 17 Lep. In spite of the many differences observed in the spectra of these stars, there appears to be a tendency in all four to show fluctuations of radial velocity which repeat themselves every four or five months. Whether this has a bearing upon the origin of the shell is not known. At present we know only that rapid axial rotation in a B-type star is required to produce

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¹ Struve and Swings, *Ap. J.*, 93, 486, 1941; Kiess, Krogdahl, Bidelman, and Hall, *Pub. A.A.S.*, 10, 227, 1942.

TABLE 1
RADIAL VELOCITIES OF PLEIONE

Date	U.T.	JD 2429	Velocity (In Km/Sec)	Observatory and Quality
1938 Dec. 16.....	1 ^h 08 ^m	248.55	+ 4.2	Y film
1940 Sept. 13.....	9 07	885.88	+ 9.1	Y
Nov. 3.....	11 22	936.97	0.0	Y
Nov. 12.....	9 45	945.91	+15.4	M
Dec. 8.....	0 37	971.53	+ 6.3	Y
		JD 2430		
1941 Jan. 7.....	5 02	001.71	+10.0	M
Aug. 4.....	10 28	210.94	+ 6.5	M film
Aug. 4.....	11 04	210.96	+ 7.3	M film
Sept. 4.....	7 41	241.82	- 1.5	Y poor
Sept. 6.....	8 10	243.84	- 5.0	Y
Sept. 20.....	8 15	257.84	+ 1.8	Y
Sept. 26.....	8 29	263.85	+ 1.2	Y
Sept. 27.....	8 03	264.84	- 1.4	Y
Oct. 15.....	9 33	282.90	- 2.3	Y underexposed
Oct. 16.....	6 33	283.77	+ 1.0	Y
Oct. 24.....	6 08	291.76	+ 1.8	Y
Oct. 24.....	10 10	291.92	+ 7.1	Y
Nov. 1.....	10 57	299.96	+10.2	M
Nov. 1.....	12 19	300.01	+15.9	M
Nov. 2.....	8 38	300.86	+ 9.8	M
Nov. 18.....	6 40	316.78	+11.0	Y poor
Nov. 19.....	6 32	317.77	+ 7.1	Y
Dec. 11.....	3 12	339.63	+ 6.8	Y
Dec. 15.....	2 10	343.59	+ 1.7	Y
1942 Jan. 5.....	1 40	364.57	+ 6.7	Y
Jan. 8.....	3 15	367.64	- 3.2	M film, poor
Jan. 8.....	4 15	367.68	+15.0	M
Jan. 14.....	2 20	373.60	+ 3.0	Y
Jan. 23.....	0 12	382.51	- 1.8	Y
Jan. 24.....	0 30	383.52	+ 2.3	Y
Jan. 27.....	7 28	386.81	+ 2.6	M
Jan. 31.....	3 53	390.66	+13.1	M film, poor
Feb. 8.....	0 44	398.53	+ 7.3	Y
Feb. 20.....	1 25	410.56	+ 4.9	Y
Apr. 13.....	1 43	462.57	- 3.6	Y
Aug. 25.....	8 52	596.87	+ 7.8	Y
Sept. 16.....	6 50	618.78	+ 8.3	Y
Sept. 17.....	8 33	619.86	+ 9.8	Y
Sept. 25.....	8 09	627.84	+13.0	Y
Sept. 27.....	7 18	629.80	+ 7.9	Y
Sept. 28.....	7 54	630.83	+ 4.8	Y
Oct. 6.....	8 07	638.84	+ 7.7	Y
Oct. 6.....	9 27	638.89	+10.8	Y
Oct. 7.....	8 07	639.84	+ 8.7	Y
Oct. 7.....	9 32	639.90	+ 5.8	Y
Oct. 8.....	7 08	640.80	+ 4.8	Y
Oct. 8.....	8 16	640.84	+ 8.6	Y
Oct. 17.....	9 39	649.90	+ 7.5	Y
Oct. 18.....	6 35	650.77	+ 5.3	Y
Nov. 6.....	5 51	669.74	- 4.0	Y
Nov. 13.....	5 35	676.73	+ 1.1	Y
Nov. 18.....	5 18	681.72	- 3.1	Y
Nov. 25.....	5 32	688.73	- 5.6	M
Nov. 27.....	6 10	690.76	- 0.5	Y

TABLE 1—*Continued*

Date	U.T.	JD 2430	Velocity (In Km/Sec)	Plate and Quality
Dec. 4.	5 ^h 31 ^m	697.73	+ 2.2	Y
Dec. 5.	5 46	698.74	+ 1.1	Y
Dec. 11.	4 39	704.69	+ 3.9	Y
Dec. 16.	5 27	709.73	+ 4.8	Y
Dec. 25.	3 29	718.64	+ 5.6	Y
Dec. 25.	4 22	718.68	+ 4.8	Y
1943 Jan. 11.	6 30	735.77	+ 9.8	M
Jan. 20.	2 29	744.60	+ 9.7	M
Jan. 20.	4 45	744.70	+ 7.1	M film
Jan. 26.	5 32	750.73	+ 6.7	M
Jan. 28.	2 39	752.61	+10.4	M
Jan. 28.	2 42	752.61	+ 7.1	M
Jan. 29.	0 31	753.52	+ 2.9	Y
Jan. 29.	1 06	753.55	+ 8.1	M
Jan. 29.	1 08	753.55	+ 8.0	M
Jan. 30.	3 54	754.66	+ 7.1	M film
Feb. 5.	2 00	760.58	+ 9.3	Y
Feb. 16.	0 21	771.51	+ 9.4	Y
Feb. 16.	1 14	771.55	+ 4.1	Y
Feb. 18.	1 07	773.55	+ 8.7	Y
Feb. 18.	1 39	773.57	+ 5.4	Y
Feb. 23.	0 19	778.51	+12.0	Y

a shell spectrum; but, since not all rapidly rotating B stars have shells, it may be concluded that rapid rotation, though necessary, is not sufficient to produce shell absorption. The fluctuations in radial velocity may provide a clue to a further condition which is required and which, when combined with rapid rotation, would constitute a sufficient condition for the origin of a shell.²

The average velocity from all 76 plates of Pleione is

$$v_{av} = +5.5 \text{ km/sec.}$$

The radial velocity of the entire cluster of the Pleiades has not been accurately determined. The few published values lead to an average velocity of +7 or +8 km/sec, but most of them are based upon measurements of broad lines in the bright B-type stars. Until the velocity of the cluster has been accurately determined, it will not be possible to state whether the shell of Pleione is stationary or has a very small velocity of expansion.

3. The sharp absorption lines of Pleione have gradually become stronger, and there is as yet no indication that this process has been arrested. Two of our best spectrograms were measured completely: the Process plate, taken with the quartz spectrograph at McDonald on November 25, 1942, was used in the ultraviolet region and as far to the blue as λ 3750. The Process film, taken with the glass prisms at McDonald on January 30, 1943, gave the wave lengths longer than λ 3750. The two dispersions were 40 Å/mm and 20 Å/mm at λ 3933, respectively. The Process plate had somewhat better contrast than the Process film.

The spectrum of Pleione greatly resembles that of α Cygni. In the ultraviolet region the intensities of the sharp lines are even somewhat greater than in α Cygni. But the dilution effects are as conspicuous as they were in 1940.¹ Plates I, II, III, IV, and V illustrate the development of the shell spectrum. In the early stages Ni II was very

² These ideas are elaborated upon in a paper by O. Struve, *Pop. Astr.* (in press).

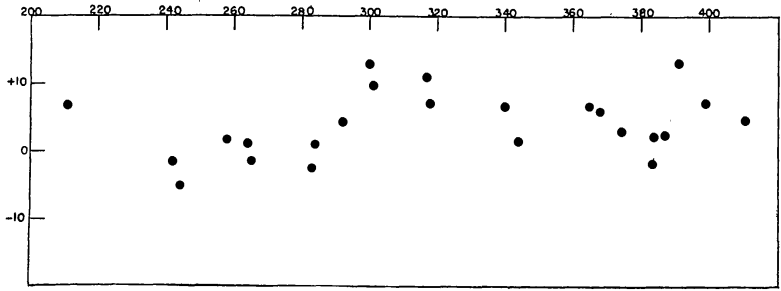


FIG. 1.—Radial velocities of Pleione in 1941-1942

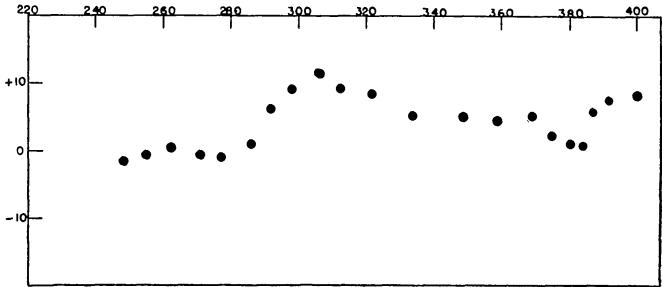


FIG. 2.—Smoothed radial velocities of Pleione in 1941-1942

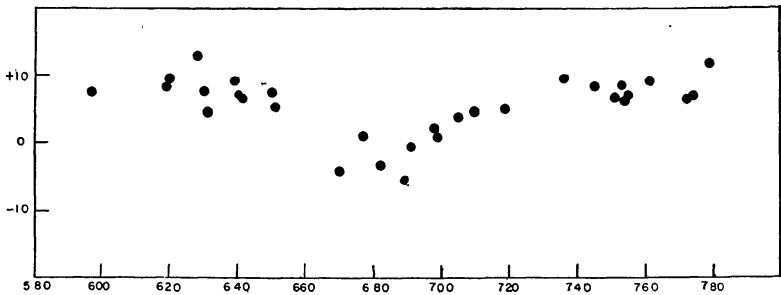


FIG. 3.—Radial velocities of Pleione in 1942-1943

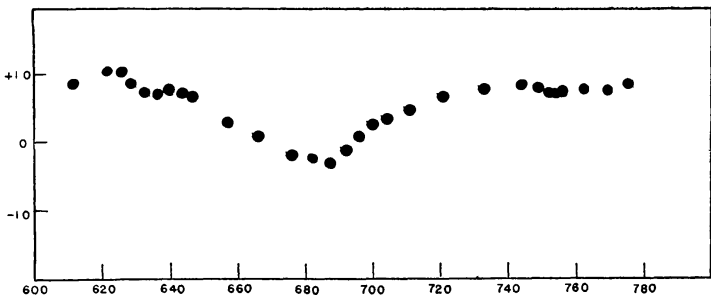


FIG. 4.—Smoothed radial velocities of Pleione in 1942-1943

TABLE 2
LIST OF LINES IN THE SPECTRUM OF PLEIONE IN 1o42-43

Wave Length	Int.	Identification*
3307.07	2	<i>Cr</i> II 07.04(50), <i>Cr</i> II 06.95(50)
3309.06	2	<i>Ti</i> II 08.81(100)
3310.70	1	<i>Cr</i> II 10.65(35)
3312.26	3	<i>Cr</i> II 12.18(40), <i>Cr</i> II 11.93(40)
3314.09	1	<i>Fe</i> II 14.00(1), <i>Cr</i> II 14.57(35), <i>Cr</i> II 14.06(18)
3315.52	1	<i>Ti</i> II 15.32(100), <i>Cr</i> II 15.29(12)
3318.19	1	<i>Ti</i> II 18.03(125)
3319.68	0	(<i>a</i> Cygni)
3321.81	1	<i>Ti</i> II 21.70(125), (<i>Fe</i> II 21.49(1)), (<i>V</i> II 21.54(150))
3323.19	5	<i>Fe</i> II 23.07(8), <i>Ti</i> II 22.94(300), (<i>Cr</i> II 23.53(8))
3324.29	4	<i>Cr</i> II 24.35(50), <i>Cr</i> II 24.06(25), <i>Cr</i> II 24.10(20)
3326.89	1	<i>Ti</i> II 26.76(125)
3328.31	1	<i>Cr</i> II 28.35(20)
3329.55	3	<i>Ti</i> II 29.46(200), (<i>Cr</i> II 29.45(4)), (<i>Fe</i> II 29.07(2))
3332.18	4	<i>Ti</i> II 32.11(125)
3335.35	4	<i>Cr</i> II 35.28(40), <i>Ti</i> II 35.19(150), <i>Cr</i> II 35.46(30)
3336.49	3	<i>Cr</i> II 36.33(40), (<i>Fe</i> II 36.34(pred.))
3337.85	1n	<i>V</i> II 37.84(200), <i>Ti</i> II 37.85(60), (<i>Fe</i> II 38.52(3))
3340.17	7	<i>Cr</i> II 39.80(50), <i>Ti</i> II 40.34(100), <i>Cr</i> II 39.90(20)
3342.32	8	<i>Cr</i> II 42.51(50), <i>Ti</i> II 41.87(300)
3343.78	1	<i>Ti</i> II 43.77(70)
3345.17	0n	<i>Zr</i> II 44.80(15)
3346.81	1	<i>Ti</i> II 46.73(60)
3347.99	2	<i>Cr</i> II 47.84(40)
3349.35	5	<i>Ti</i> II 49.41(400), <i>Ti</i> II 49.03(800), (<i>Cr</i> II 49.34(16)), (<i>Ti</i> II 48.84(12))
3350.42	1	<i>Ni</i> II 50.42(5), (<i>Ca</i> I 50.36(15)), (<i>Ti</i> II 50.52(5)), (<i>Fe</i> II 50.34(pred.))
3352.14	0	<i>Ti</i> II 52.07(15), (<i>Fe</i> II 52.40(pred.))
3353.41	2n	<i>Cr</i> II 53.12(20), <i>Sc</i> II 53.74(60)
3356.01	0	<i>Fe</i> II 56.26(m), <i>Zr</i> II 56.08(18)
3357.47	1	<i>Cr</i> II 57.40(40), <i>Zr</i> II 57.26(15), <i>Fe</i> II 57.96(0)
3358.57	3	<i>Cr</i> II 58.50(75), <i>Fe</i> II 58.25(3), (<i>Fe</i> II 58.78(pred.))
3360.20	3	<i>Fe</i> II 60.10(3), <i>Cr</i> II 60.29(100), (<i>Fe</i> II 60.31(0)), (<i>Ti</i> II 60.12(pred.))
3361.50	5	<i>Ti</i> II 61.21(600), <i>Cr</i> II 61.77(30), (<i>V</i> II 61.51(60))
3363.45	1b	<i>Cr</i> II 63.71(12)
3364.40	1b	<i>Fe</i> II 65.41(1), <i>Fe</i> II 64.22(pred.), (<i>Cr</i> II 64.72(1))
3366.38	1n	<i>Ti</i> II 66.18(50), <i>Fe</i> II 66.96(3)
3367.93	5	<i>Cr</i> II 68.05(150)
3369.23	3	<i>Fe</i> II 69.35(3), <i>Cr</i> II 69.05(18), <i>Ti</i> II 69.21(25), (<i>Sc</i> II 68.95(20))
3371.06	0	<i>Fe</i> I 70.79(300), <i>Co</i> II 70.94(50), (<i>Cr</i> II 71.46(1)), (<i>Cr</i> II 70.71(0))
3372.80	3	<i>Ti</i> II 72.80(400)
3374.27	1n	<i>Ti</i> II 74.35(30), <i>Ni</i> II 73.98(4), <i>Zr</i> II 74.71(15)
3376.81	0	<i>Cr</i> II 76.72(5), (<i>Cr</i> II 76.27(10))
3378.33	2	<i>Cr</i> II 78.34(25)
3380.01	10n	<i>Cr</i> II 79.82(60), <i>Cr</i> II 79.37(30), <i>Ti</i> II 80.28(150)
3381.12	1	<i>Fe</i> II 81.00(4), (<i>Fe</i> II 81.36(pred.)), (<i>La</i> II 80.89(250))
3382.64	3	<i>Cr</i> II 82.68(60)
3383.85	4	<i>Ti</i> II 83.76(300)
3387.87	4	<i>Ti</i> II 87.84(125), <i>Fe</i> II 88.13(2), <i>Co</i> II 87.72(60), (<i>Cr</i> II 87.73(5))
3388.90	1	<i>Ti</i> II 88.75(35)
3391.41	2	<i>Fe</i> II 91.30(1), <i>Cr</i> II 91.43(35)

* Certain *Cr* II lines of laboratory intensity 0, 1, 2, 3, have been written between parentheses; they correspond to a slightly different intensity scale and are actually stronger than would appear from their intensities.

TABLE 2—Continued

Wave Length	Int.	Identification*
3392.99	1	<i>Cr</i> II 93.00(35)
3394.33	6	<i>Cr</i> II 94.32(35), <i>Ti</i> II 94.57(200)
3397.85	0n	<i>Fe</i> II 98.35(4), <i>Ni</i> II 97.82(1)
3399.73	1n	<i>Cr</i> II 99.54(18), (<i>Zr</i> II 99.36(10)), (<i>Cr</i> II 00.08(2))
3402.46	1	<i>Ti</i> II 02.42(90), <i>Cr</i> II 02.43(25)
3403.29	4	<i>Cr</i> II 03.32(100)
3405.05	1n	<i>Zr</i> II 04.84(12), (<i>V</i> II 04.43(80)), (<i>Cr</i> II 05.3(1n))
3407.22	3n	<i>Ni</i> II 07.30(8), <i>Ti</i> II 07.20(50)
3408.73	4	<i>Cr</i> II 08.76(150)
3415.82	2	<i>Fe</i> II 16.02(5), (<i>Co</i> II 15.78(75))
3418.72	0	(<i>Fe</i> I 18.51(150))
3421.12	5	<i>Cr</i> II 21.20(75)
3422.64	5	<i>Cr</i> II 22.74(125), (<i>Ti</i> II 22.66(10))
3424.22	0	(<i>Co</i> II 23.85(75)), (<i>Cr</i> II 24.65(1))
3425.59	1	<i>Fe</i> II 25.58(3)
3428.27	0nn	<i>Cr</i> II 28.94(7), (<i>Cr</i> II 27.92(1)), (<i>Fe</i> II 28.64(pred.))
3430.37	0nn	<i>Zr</i> II 30.53(30), <i>Cr</i> II 30.42(3), (<i>Fe</i> II 30.15(pred.))
3433.31	6	<i>Cr</i> II 33.30(75)
3436.03	1	<i>Fe</i> II 36.11(5)
3437.85	0n	<i>Zr</i> II 38.23(100), (<i>Cr</i> II 37.93(2))
3439.07	1	<i>Mn</i> II 38.98(20)
3440.82	1	<i>Fe</i> I 40.61(500), (<i>Cr</i> II 40.60(1))
3441.94	4	<i>Mn</i> II 41.98(100), (<i>Fe</i> II 42.24(3)), (<i>Fe</i> II 41.90(0))
3444.26	4	<i>Ti</i> II 44.31(150), (<i>Cr</i> II 44.34(4))
3446.12	1	<i>Co</i> II 46.40(100)
3448.01	0	<i>Fe</i> II 48.43(1)
3449.46	1	(<i>Cr</i> II 49.28(2))
3451.12	1	<i>Fe</i> II 51.23(2), <i>Fe</i> II 51.32(2), (<i>Fe</i> II 51.61(2))
3452.37	1	<i>Ti</i> II 52.47(100)
3453.95	2	<i>Ni</i> II 54.16(5), <i>Fe</i> II 53.59(2)
3454.66	1	<i>Cr</i> II 54.98(35)
3456.81	2nn	<i>Fe</i> II 56.93(5), <i>Ti</i> II 56.39(125), <i>Cr</i> II 57.62(30), <i>V</i> II 57.15(300)
3460.27	4	<i>Mn</i> II 60.31(75), (<i>Mn</i> II 60.04(8)), (<i>Cr</i> II 59.29(25)), (<i>Cr</i> II 60.03(1))
3461.41	3	<i>Ti</i> II 61.50(125)
3464.19	1	<i>Fe</i> II 63.97(1), <i>Fe</i> II 64.50(3), <i>Mn</i> II 64.04(7), (<i>Sr</i> II 64.47(50)), (<i>Cr</i> II 64.02(4))
3465.58	3	<i>Ti</i> II 65.56(60), (<i>Ni</i> II 65.62(1))
3468.66	4	<i>Fe</i> II 68.68(8)
3471.38	3n	<i>Cr</i> II 72.07(25), <i>Ni</i> II 71.35(2), <i>Fe</i> II 70.24(1)
3473.98	3	<i>Mn</i> II 74.04(50), <i>Mn</i> II 74.12(40), <i>Fe</i> II 73.82(2)
3475.61	1	<i>Cr</i> II 75.13(20), <i>Fe</i> II 75.74(pred.), <i>Fe</i> II 75.25(pred.)
3477.16	3	<i>Ti</i> II 77.18(100), (<i>Ti</i> II 76.98(8))
3479.71	1	<i>Fe</i> II 79.91(2), (<i>Zr</i> II 79.39(30)), (<i>V</i> II 79.84(80))
3481.04	0	<i>Ti</i> II 80.90(25), <i>Zr</i> II 81.14(35)
3482.82	3	<i>Mn</i> II 82.90(40), (<i>Cr</i> II 82.58(12))
3484.10	1	<i>Fe</i> II 84.35(1), <i>Cr</i> II 84.15(20)
3486.31	1	<i>V</i> II 85.92(250)
3487.95	0b	<i>Fe</i> II 87.99(3), <i>Ca</i> I 87.60(100)
3488.61	2b	<i>Mn</i> II 88.68(40), (<i>Cr</i> II 89.07(2))
3490.92	3	<i>Ti</i> II 91.05(70), <i>Fe</i> I 90.57(400)
3493.30	5	<i>Fe</i> II 93.47(10), (<i>V</i> II 93.16(150))
3494.69	0	<i>Fe</i> II 94.67(5), (<i>Cr</i> II 94.52(4))
3495.78	3	<i>Mn</i> II 95.83(40), <i>Fe</i> II 95.62(4), <i>Cr</i> II 95.56(20) (<i>Cr</i> II 95.37(25)), (<i>V</i> II 96.09(80))
3497.49	3	<i>Mn</i> II 97.54(25), <i>Mn</i> II 96.81(20), <i>Fe</i> II 97.81(m), <i>V</i> II 97.03(200), (<i>Fe</i> II 97.73(pred.))
3500.03	2	<i>Fe</i> II 99.88(4), <i>Ti</i> II 00.34(35)

TABLE 2—Continued

Wave Length	Int.	Identification*
3501.76	2	<i>Co</i> II 01.73(200), (<i>Cr</i> II 01.53(1))
3503.32	1	<i>Fe</i> II 03.47(2), (<i>Fe</i> II 03.07(0))
3504.82	5	<i>Ti</i> II 04.89(150), (<i>V</i> II 04.43(400))
3507.43	2n	<i>Fe</i> II 07.39(3), (<i>Fe</i> II 08.21(1))
3510.60	3	<i>Ti</i> II 10.84(125)
3511.73	2	<i>Cr</i> II 11.84(35)
3513.95	4	<i>Ni</i> II 13.93(8), (<i>Fe</i> I 13.82(400))
3515.68	1	<i>Fe</i> II 15.82(12), (<i>Cr</i> II 15.37(1))
3517.02	2	<i>V</i> II 17.30(800)
3518.90	0	(<i>Cr</i> II 18.62(3))
3520.32	2	<i>Ti</i> II 20.25(18), (<i>V</i> II 20.02(120))
3521.47	1	<i>Fe</i> I 21.26(300), (<i>V</i> II 21.84(90))
3523.68	1	
3524.70	1	<i>V</i> II 24.71(200), <i>Ti</i> II 24.87(5), (<i>Ni</i> I 24.54(1000))
3526.40	1n	<i>Fe</i> I 26.04(80), <i>Fe</i> I 26.17(50), <i>Fe</i> I 26.68(80)
3528.04	0	(<i>Cr</i> II 28.26(1))
3530.38	1n	<i>V</i> II 30.76(500), (<i>Cr</i> II 30.72(1)), (<i>Cr</i> II 30.05(1))
3533.53	1	<i>Ti</i> II 33.87(35), (<i>Fe</i> II 33.19(pred.))
3535.47	4	<i>Ti</i> II 35.41(125), <i>Fe</i> II 35.63(2), (<i>Sc</i> II 35.73(30)), (<i>Mg</i> II 35.04(8)), (<i>Cr</i> II 35.50(1))
3538.61	1	<i>Mg</i> II 38.86(6), (<i>Cr</i> II 38.47(1))
3541.59	0	(<i>Fe</i> I 42.08(150)), (<i>Fe</i> I 41.09(200)), (<i>V</i> II 41.34(50))
3545.13	2	<i>V</i> II 45.19(1000), (<i>Co</i> II 45.03(25))
3547.88	1	
3549.17	1	<i>Fe</i> II 49.03(1), <i>Y</i> II 49.01(100), <i>Ti</i> II 49.27(pred.)
3552.10	0n	<i>Zr</i> II 51.94(18), <i>Cr</i> II 52.42(2)
3556.89	2	<i>V</i> II 56.80(1500), (<i>Zr</i> II 56.61(30))
3558.39	1	<i>Fe</i> I 58.52(400), (<i>Sc</i> II 58.54(40))
3561.26	2n	<i>Ti</i> II 61.57(20), (<i>Cr</i> II 60.91(1))
3564.73	1n	(<i>Cr</i> II 65.31(5)), (<i>Cr</i> II 64.31(1))
3566.15	2	<i>Fe</i> II 66.15(3), <i>Fe</i> II 66.05(2), <i>Ti</i> II 65.99(25), <i>V</i> II 66.18(200)
3567.78	1	<i>Sc</i> II 67.70(40)
3570.25	1	<i>Fe</i> I 70.10(300)
3572.66	1	<i>Sc</i> II 72.52(50), (<i>Zr</i> II 72.47(30))
3573.98	1	<i>Ti</i> II 73.74(40)
3576.63	5	<i>Ni</i> II 76.76(3), (<i>Sc</i> II 76.34(45)), (<i>Zr</i> II 76.88(20))
3578.98	0n	<i>Cr</i> I 78.69(500), <i>Ti</i> II 78.69(5)
3581.14	3	<i>Fe</i> I 81.19(1000), (<i>Sc</i> II 80.93(40))
3582.18	1n	
3585.37	8	<i>Cr</i> II 85.31(60), <i>Cr</i> II 85.54(40)
3587.50	1	<i>Ti</i> II 87.13(25), <i>Al</i> II 87.44(80)
3589.69	3n	<i>V</i> II 89.74(1000), (<i>Sc</i> II 89.63(12))
3592.06	1	<i>V</i> II 92.01(800)
3593.35	1	<i>V</i> II 93.32(600), <i>Ti</i> II 93.09(30), <i>Cr</i> I 93.49(500)
3595.94	4	<i>Ti</i> II 96.05(125)
3597.67	0	<i>Ni</i> I 97.70(1000), (<i>Cr</i> II 97.55(1))
3601.74	0n	(<i>Y</i> II 01.92(100))
3603.72	5	<i>Cr</i> II 03.80(40), <i>Cr</i> II 03.86(20), <i>Cr</i> II 03.61(20)
3605.77	1n	<i>Fe</i> I 05.46(300), <i>Cr</i> I 05.33(500)
3607.40	1	(<i>Cr</i> II 07.32(1))
3608.86	2	<i>Fe</i> I 08.86(500), (<i>Ni</i> II 08.7(pred.)), (<i>Cr</i> II 08.66(3))
3610.38	0nn	<i>Ni</i> I 10.46(1000), <i>Fe</i> II 10.33(pred.), (<i>Fe</i> I 10.16(100))
3613.59	3	<i>Cr</i> II 13.26(15), <i>Cr</i> II 13.21(20), <i>Sc</i> II 13.84(70), (<i>Ti</i> II 13.33(pred.))
3614.91	2	<i>Fe</i> II 14.87(5), (<i>Zr</i> II 14.79(18))
3618.99	3	<i>Fe</i> I 18.77(400), <i>V</i> II 18.92(200)
3621.25	4	<i>Fe</i> II 21.27(6), <i>V</i> II 21.20(150), (<i>Co</i> II 21.22(100))
3624.77	4	<i>Ti</i> II 24.83(125), <i>Fe</i> II 24.89(5), <i>Fe</i> II 24.69(2)

TABLE 2—Continued

Wave Length	Int.	Identification*
3625.67	1	V II 25.61(50)
3627.37	0	Fe II 27.17(1), V II 27.71(60), Ti II 27.71(12)
3628.98	0	V II 28.71(100)
3631.44	8	Cr II 31.49(50), Cr II 31.72(40), Fe I 31.46(500)
3635.27	0n	(Ti II 35.64(pred.))
3637.90	0	(Fe I 38.30(100))
3641.18	3	Ti II 41.33(150)
3642.86	1	Sc II 42.78(50), Cr II 43.22(10)
3645.41	1	Sc II 45.31(50), Fe II 45.78(pred.), (La II 45.41(200))
3647.70	1	Fe I 47.84(500), (Cr II 47.40(8))
3649.25	0	Fe I 49.51(100), (?Cr II 49.66(2)), (?Cr II 49.20(1))
3650.54	0	Cr II 50.37(40)
3651.78	1	Cr II 51.68(12), Sc II 51.80(85)
3658.05	1	Cr II 58.19(20)
3659.73	3	Ti II 59.76(150)
3661.20	1	H 31 61.22(...)
3662.14	1	H 30 62.26(...), Ti II 62.24(100)
3663.24	1	H 29 63.40(...)
3664.80	2	H 28 64.70(...), Cr II 64.95(30)
3666.06	3	H 27 66.10(...)
3667.69	3	H 26 67.68(...)
3669.49	4	H 25 69.47(...), (V II 69.41(300))
3671.44	4	H 24 71.48(...)
3673.75	4	H 23 73.76(...)
3676.34	5	H 22 76.36(...)
3677.73	4	Cr II 77.69(40), Cr II 77.86(50), Cr II 77.93(30)
3679.35	5	H 21 79.35(...)
3682.72	6	H 20 82.81(...)
3685.19	5	Ti II 85.19(700), (Cr II 84.25(25))
3686.79	7	H 19 86.83(...), (Cr II 86.67(20))
3691.53	10	H 18 91.56(2)
3694.42	1n	Fe I 94.01(400), Fe I 95.05(200)
3697.14	15	H 17 97.15(3), (Cr II 98.00(35))
3699.82	1n
3700.89	1n	Fe I 01.09(300), (Cr II 00.73(1))
3703.85	15	H 16 03.86(4)
3705.99	3n	Ca II 06.03(40), Ti II 06.23(125)
3707.69	1	(Fe I 07.82(80)), (Fe I 07.92(80)), (Mn II 08.06(1))
3709.35	1n	Fe I 09.25(600), Zr II 09.27(60), (V II 09.33(40)), (Mn II 09.88(1))
3711.93	10	H 15 11.98(5)
3712.62	3	Cr II 12.97(35)
3715.28	5	V II 15.48(1200), Cr II 15.19(20), Cr II 15.45(20)
3718.54	0	(V II 18.16(60)), (Fe I 18.41(80))
3720.09	2	Fe I 19.93(1000), (Cr II 19.72(1))
3721.97	18	H 14 21.95(6), (Ti II 21.64(125))
3723.69	1	Cr II 23.40(15), Ti II 23.63(15), Ti II 24.11(18)
3725.12	1	Fe II 25.30(3)
3727.40	3n	Cr II 27.37(40), V II 27.35(1000), Fe II 27.04(m), Fe I 27.62(200), (Zr II 27.72(10))
3732.70	0n	V II 32.76(800), Fe I 33.32(400), Fe I 32.40(200)
3734.47	20	H 13 34.37(8), (Fe I 34.87(1000))
3736.95	3n	Ca II 36.90(50), Fe I 37.13(1000), (Cr II 37.55(10))
3738.11	1n	Cr II 38.38(25)
3741.62	4	Ti II 41.64(200)
3743.16	1	Fe I 43.36(200)
3745.83	3	V II 45.81(800), Fe I 45.56(500), (Zr II 45.97(40))
3748.56	5	Fe II 48.49(8), Fe I 48.26(500), (Cr II 48.68(7)), (Ti II 48.00(25))

TABLE 2—Continued

Wave Length	Int.	Identification*
3750.16	13	<i>H</i> 12 50.15(10)
3754.36	2n	<i>Cr</i> II 54.59(20), <i>Fe</i> II 55.56(4), <i>Fe</i> I 53.61(150)
3757.73	3	<i>Ti</i> II 57.69(100), <i>Fe</i> I 58.23(700)
3759.32	5	<i>Ti</i> II 59.29(400), <i>Fe</i> II 59.46(6)
3761.40	6	<i>Ti</i> II 61.32(300)
3761.89	0	<i>Ti</i> II 61.89(15), <i>Cr</i> II 61.90(8), <i>Cr</i> II 61.69(7)
3762.91	0	<i>Fe</i> II 62.89(5)
3763.88	1	<i>Fe</i> I 63.79(500), <i>Fe</i> II 64.09(pred.)
3765.60	1	<i>Cr</i> II 65.62(8), (<i>Cr</i> II 65.28(3))
3767.41	2	<i>Fe</i> I 67.19(500)
3769.59	2	<i>Ni</i> II 69.45(5)
3770.65	15	<i>H</i> II 70.63(15), (<i>V</i> II 70.97(400))
3774.28	1	<i>Y</i> II 74.34(300)
3776.06	2	<i>Ti</i> II 76.06(60)
3778.32	1	<i>V</i> II 78.36(100), <i>Cr</i> II 78.69(6), (<i>Fe</i> II 78.37(pred.))
3779.40	0	<i>Fe</i> I 79.45(100), (<i>Cr</i> II 79.06(1))
3781.39	1	<i>Fe</i> II 81.51(1)
3783.28	2n	<i>Fe</i> II 83.35(4), (<i>Cr</i> II 83.56(2))
3786.48	1n	(<i>Fe</i> I 86.68(125)), (<i>Fe</i> I 86.18(100)), (<i>Ti</i> II 86.33(pred.))
3787.57	1	<i>Fe</i> I 87.88(500), <i>V</i> II 87.23(150)
3788.62	1	<i>Y</i> II 88.70(200)
3794.72	1n	<i>Fe</i> I 95.00(500), <i>La</i> II 94.77(500), (<i>V</i> II 94.37(50)), (<i>Cr</i> II 95.06(1?))
3797.92	15	<i>H</i> 10 97.91(20)
3813.35	1	<i>Ti</i> II 13.39(20), <i>Fe</i> I 12.96(400)
3814.50	2n	<i>Fe</i> II 14.12(4), <i>Ti</i> II 14.59(35), <i>Cr</i> II 14.00(12)
3815.55	1n	<i>Fe</i> I 15.84(700), <i>V</i> II 15.38(200), (<i>Cr</i> II 15.77(2))
3818.47	0n	<i>Y</i> II 18.35(60)
3820.58	2n	<i>Fe</i> I 20.43(800), (<i>Cr</i> II 20.48(2))
3824.84	2n	<i>Fe</i> II 24.91(4)
3825.84	1	<i>Fe</i> I 25.88(500)
3827.41	1n	<i>Fe</i> II 27.08(4), <i>Fe</i> I 27.82(200)
3829.27	2	<i>Mg</i> I 29.35(100), (<i>Fe</i> II 28.86(?2))
3832.69	3n	<i>Mg</i> I 32.31(250), <i>Fe</i> II 32.96(?2), (<i>Cr</i> II 32.74(1)), (<i>Y</i> II 32.89(100))
3835.39	10	<i>H</i> 9 35.40(40)
3838.15	3	<i>Mg</i> I 38.26(300), <i>Fe</i> II 38.04(?2)
3840.74	2n	<i>Fe</i> I 40.44(400), <i>Fe</i> I 41.05(500)
3843.02	1	<i>Sc</i> II 43.00(20), <i>Zr</i> II 43.03(30), <i>Mn</i> II 42.98(1), (<i>Cr</i> II 42.66(1))
3844.56	1
3845.17	1	<i>Fe</i> II 45.18(m), (<i>Cr</i> II 45.16(1))
3847.32	0	<i>V</i> II 47.32(100)
3848.60	0	(<i>Mg</i> II 48.24(10))
3849.82	2	<i>Fe</i> I 49.97(500), <i>Ni</i> II 49.58(2)
3851.94	0n	<i>Fe</i> I 50.82(200), <i>Fe</i> I 52.57(150)
3854.26	0	(<i>Si</i> II 53.67(3))
3855.96	2	<i>Si</i> II 56.03(8)
3859.83	2n	<i>Fe</i> I 59.91(1000)
3861.15	1	<i>Fe</i> II 60.91(3), (<i>Cr</i> II 61.34(1))
3862.48	1n	<i>Si</i> II 62.59(6)
3863.78	1n	<i>Fe</i> II 63.95(1), <i>Fe</i> II 63.41(1), <i>V</i> II 63.81(60)
3865.38	1	<i>Cr</i> II 65.59(75), <i>Fe</i> I 65.53(600)
3866.69	1n	<i>V</i> II 66.74(60), <i>Cr</i> II 66.54(7), <i>Cr</i> II 66.01(5)
3867.49	0	<i>Fe</i> I 67.22(150), (<i>Cr</i> II 67.86(1)), (<i>Cr</i> II 67.80(1))
3871.44	0	<i>La</i> II 71.65(200), <i>Fe</i> I 71.75(100)
3872.51	2n	<i>Fe</i> I 72.50(300), (<i>Cr</i> II 72.57(1?)), <i>Fe</i> II 72.76(pred.)
3878.34	3n	<i>Fe</i> I 78.57(300), <i>Fe</i> I 78.02(400), <i>V</i> II 78.71(300), (<i>Y</i> II 78.30(20))

TABLE 2—Continued

Wave Length	Int.	Identification*
3882.16.....	2	<i>Ni</i> II 81.92(1)
3889.12.....	10	<i>H</i> 8 89.05(60)
3892.87.....	0	(<i>S</i> II 92.32(35), (<i>Cr</i> II 93.31(1))
3895.92.....	1	<i>Fe</i> I 95.66(400), <i>V</i> II 96.15(60)
3899.30.....	1	<i>V</i> II 99.14(200), <i>Fe</i> I 99.71(500)
3900.57.....	4	<i>Ti</i> II 00.54(100), <i>Al</i> II 00.68(200)
3903.20.....	2	<i>V</i> II 03.27(250), <i>Fe</i> I 02.95(500)
3905.96.....	3	<i>Fe</i> II 06.04(5), <i>Cr</i> II 05.64(25), <i>Si</i> I 05.53(20), <i>Fe</i> I 06.48(300)
3907.19.....	1	(<i>Cr</i> II 07.36(1)), (<i>Sc</i> I 07.48(125))
3913.50.....	5	<i>Ti</i> II 13.46(70), (<i>Fe</i> I 13.63(100))
3914.26.....	1	<i>Fe</i> II 14.48(2), <i>V</i> II 14.33(250)
3915.38.....	0	(<i>Cr</i> II 15.58(1))
3916.38.....	1	<i>V</i> II 16.42(200), (<i>Fe</i> I 16.73(100)), <i>La</i> II 16.07(300)
3919.87.....	0n	<i>Fe</i> I 20.26(500)
3923.03.....	1	<i>Fe</i> I 22.91(600)
3927.95.....	0	<i>Fe</i> I 27.92(500)
3930.38.....	1	<i>Fe</i> I 30.31(600), (<i>Fe</i> II 30.31(pred.))
3932.17.....	0	<i>Ti</i> II 32.02(30)
3933.74.....	10	<i>Ca</i> II 33.67(600)
3935.72.....	1n	<i>Fe</i> II 35.94(6)
3938.46.....	2n	<i>Fe</i> II 38.29(2), <i>Fe</i> II 38.97(4)
3941.06.....	0n	<i>Fe</i> I 40.82(150)
3943.88.....	1n	(<i>Al</i> I 44.03(2000)), (<i>Mn</i> II 43.82(1)), (<i>Cr</i> II 43.64(1))
3945.11.....	1	(<i>Cr</i> II 45.11(1)), (<i>Fe</i> II 45.21(pred.))
3947.21.....	1	<i>O</i> I 47.33(300), (<i>Fe</i> I 47.53(70))
3949.85.....	0	<i>Fe</i> I 49.96(150)
3951.75.....	1n	<i>V</i> II 51.97(500), (<i>Fe</i> I 51.17(150))
3956.22.....	1n	<i>Fe</i> I 56.68(150), <i>Fe</i> I 56.46(100)
3960.97.....	1n	<i>Fe</i> II 60.89(3), (<i>Al</i> I 61.53(3000))
3968.56.....	8	<i>Ca</i> II 68.47(500)
3970.15.....	15	<i>He</i> 70.07(80)
3973.73.....	1n	<i>Fe</i> II 74.16(3), <i>V</i> II 73.64(300), <i>Ca</i> I 73.71(200)
3977.68.....	0	<i>Fe</i> I 77.74(300), <i>V</i> II 77.73(60)
3979.59.....	1	<i>Cr</i> II 79.51(20)
3981.87.....	1	<i>Fe</i> I 81.77(150), (<i>Fe</i> II 81.61(pred.)), (<i>Ti</i> II 82.01(3))
3983.79.....	0	<i>Fe</i> I 83.96(200), (<i>Cr</i> I 83.91(200))
3985.86.....	0	<i>Mn</i> II 86.01(1), (<i>Fe</i> I 85.39(125)), (<i>Fe</i> I 86.17(125)), (<i>V</i> II 85.78(30))
3987.33.....	1
3996.99.....	1	<i>V</i> II 97.13(200), <i>Fe</i> I 97.40(300)
3999.03.....	1	<i>Zr</i> II 98.98(30), (<i>S</i> II 98.79(60))
4002.61.....	1n	<i>Fe</i> II 02.55(3), <i>Fe</i> II 02.07(2), <i>Cr</i> II 02.48(5), <i>Cr</i> II 03.33(25), <i>V</i> II 02.94(80).
4004.35.....	0	<i>Fe</i> II 04.15(pred.)
4005.64.....	3n	<i>V</i> II 05.71(800), <i>Fe</i> I 05.25(250)
4008.28.....	0	(<i>Fe</i> II 07.72(pred.))
4012.42.....	4	<i>Cr</i> II 12.50(30), <i>Ti</i> II 12.39(50), <i>Fe</i> II 12.47(1)
4015.66.....	1	<i>Ni</i> II 15.50(1)
4023.40.....	1	<i>V</i> II 23.39(600), (<i>Sc</i> I 23.69(100))
4024.89.....	4	<i>Fe</i> II 24.55(5), <i>Fe</i> I 24.74(120), <i>Ti</i> II 25.14(25)
4028.34.....	3	<i>Ti</i> II 28.35(80)
4029.73.....	1	(<i>Zr</i> II 29.68(20)), (<i>Fe</i> I 29.64(80))
4030.77.....	0	<i>Fe</i> I 30.49(120), <i>Mn</i> I 30.75(500), (<i>Cr</i> II 30.68(3))
4032.97.....	0	<i>Fe</i> II 32.95(3), <i>Mn</i> I 33.07(400)
4035.53.....	1	<i>V</i> II 35.63(400), (? <i>Cr</i> II 35.15(1))
4041.23.....	0	(<i>Mn</i> I 41.36(100)), (<i>Fe</i> II 41.64(pred.))
4044.11.....	0	<i>Fe</i> II 44.01(m)
4045.79.....	2	<i>Fe</i> I 45.81(400), (<i>Zr</i> II 45.63(15))

TABLE 2—Continued

Wave Length	Int.	Identification*
4048.73	2	<i>Fe</i> II 48.83(3), (<i>Zr</i> II 48.68(25)), (<i>Cr</i> II 49.14(18))
4051.25	1	<i>V</i> II 51.34(100), (<i>Fe</i> II 51.21(pred.))
4052.21	0	(<i>Cr</i> II 51.97(12))
4053.92	4	<i>Ti</i> II 53.84(25), (<i>V</i> II 53.59(60)), (<i>Cr</i> II 54.11(8))
4055.91	1	(<i>Cr</i> II 56.07(4)), (<i>Ti</i> II 56.21(2))
4057.43	0	<i>Fe</i> II 57.46(2)
4061.84	0	<i>Fe</i> II 61.79(1)
4063.28	2n	<i>Fe</i> I 63.60(400)
4066.93	3	<i>Ni</i> II 67.05(3), (<i>Fe</i> I 66.98(100))
4070.87	0	<i>Cr</i> II 70.90(10)
4071.51	2	<i>Fe</i> I 71.74(300)
4075.51	0	(<i>Cr</i> II 75.63(pred.)), (<i>Si</i> II 75.45(2))
4077.63	1	<i>Sr</i> II 77.71(500), (<i>La</i> II 77.35(300)), (<i>Fe</i> II 77.16(3))
4081.86	1	(<i>Cr</i> II 82.30(10))
4085.51	1	<i>Fe</i> I 85.32(100)
4101.79	20	<i>H</i> δ 01.74(100)
4107.19	0	<i>Fe</i> I 07.49(120)
4111.10	0	<i>Cr</i> II 11.01(18)
4118.96	0n	<i>Fe</i> I 18.55(200), (<i>Co</i> I 18.77(1000))
4122.51	3	<i>Fe</i> II 22.64(4)
4128.10	2n	<i>Si</i> II 28.05(8), <i>Fe</i> II 28.73(3)
4131.69	2n	<i>Si</i> II 30.88(10), <i>Fe</i> I 32.06(300), (<i>Mn</i> II 32.28(1))
4134.73	1	<i>Fe</i> I 34.68(150)
4136.71	1	<i>Mn</i> II 36.91(2), (<i>Fe</i> I 37.00(100))
4143.67	2n	<i>Fe</i> I 43.87(400), <i>Fe</i> I 43.42(200)
4145.73	1	<i>Cr</i> II 45.77(25), (<i>S</i> II 45.10(250))
4147.20	0	(<i>Fe</i> I 47.67(200))
4148.86	1	(<i>Fe</i> I 49.37(100)), (<i>Zr</i> II 49.22(75))
4151.01	0n	<i>Cr</i> II 51.00(5), <i>Zr</i> II 50.97(10), <i>N</i> I 51.46(1000)
4155.81	1	(<i>Zr</i> II 56.24(15))
4158.31	0	<i>Fe</i> I 57.79(150), <i>Fe</i> I 58.80(100)
4161.09	3n	<i>Ti</i> II 61.54(30), <i>Zr</i> II 61.20(20), <i>Cr</i> II 61.05(2), (<i>Al</i> II 60.24(12))
4163.65	4	<i>Ti</i> II 63.65(150)
4167.92	1	(<i>Mg</i> I 67.39(6)), (<i>Mg</i> I 67.65(5))
4171.90	4	<i>Ti</i> II 71.90(70), (<i>Cr</i> II 71.92(3))
4173.43	6	<i>Fe</i> II 73.45(8), <i>Ti</i> II 73.55(40)
4175.99	0	<i>Fe</i> I 75.64(100), <i>Fe</i> I 76.57(100)
4177.71	3	<i>Fe</i> I 77.60(100), <i>Fe</i> II 77.70(pred.), (<i>Y</i> II 77.54(125))
4178.93	6	<i>Fe</i> II 78.85(8), (<i>Cr</i> II 79.43(12))
4181.68	0	<i>Fe</i> I 81.76(200), (<i>Cr</i> II 81.50(1))
4184.19	0	<i>Ti</i> II 84.33(20)
4187.36	0n	<i>Fe</i> I 87.04(250), <i>Fe</i> I 87.80(200), (<i>Zr</i> II 86.70(12))
4195.20	1	<i>Fe</i> I 95.34(150), <i>Cr</i> II 95.41(10)
4198.60	1	<i>Fe</i> I 98.31(250), <i>Fe</i> I 99.10(300), (<i>Si</i> II 98.25(3))
4202.12	3	<i>Fe</i> I 02.03(400), (<i>V</i> II 02.35(150))
4204.90	1	<i>V</i> II 05.08(250)
4208.28	0n	<i>Fe</i> I 08.61(100), <i>Zr</i> II 08.99(30)
4211.46	0n	<i>Fe</i> I 10.35(300), <i>Zr</i> II 11.88(12)
4215.59	2	<i>Sr</i> II 15.52(400)
4219.03	1	<i>Fe</i> I 19.36(250)
4222.28	0	<i>Fe</i> I 22.22(200), (<i>Cr</i> II 22.00(1))
4225.32	1	<i>V</i> II 25.23(120), <i>Cr</i> II 24.85(20), (<i>Fe</i> I 25.46(80))
4226.89	2	<i>Ca</i> I 26.73(500), <i>Al</i> II 26.81(35), (<i>Fe</i> I 27.43(300))
4233.25	10	<i>Fe</i> II 33.17(11), (<i>Cr</i> II 33.25(10))
4238.98	0	<i>Fe</i> I 38.82(200), (<i>Cr</i> II 39.31(0))
4242.29	3	<i>Cr</i> II 42.38(30)
4244.77	0	<i>Ni</i> II 44.80(1), (<i>Cr</i> II 45.08(1))
4246.73	4	<i>Sc</i> II 46.83(500)

TABLE 2—Continued

Wave Length	Int.	Identification*
4250.46	0	<i>Fe</i> I 50.79(400), <i>Fe</i> I 50.13(250), (<i>Mo</i> II 50.69(125)), (<i>Cr</i> II 50.51(1))
4252.67	1	<i>Cr</i> II 52.62(10), (<i>Mn</i> II 53.02(2))
4254.07	0	<i>Cr</i> I 54.35(5000)
4257.99	1	<i>Fe</i> II 58.15(3), (<i>Zr</i> II 58.05(12))
4260.32	1	<i>Fe</i> I 60.48(400)
4261.85	2	<i>Cr</i> II 61.92(20)
4268.57	0	(<i>Fe</i> I 67.83(125)), (<i>Cr</i> II 69.28(10))
4271.34	1	<i>Fe</i> I 71.76(1000), <i>Fe</i> I 71.16(400)
4273.14	1	<i>Fe</i> II 73.32(3)
4274.35	0	<i>Cr</i> I 74.80(4000)
4275.63	2	<i>Cr</i> II 75.57(30), (<i>La</i> II 75.66(100))
4277.92	1	<i>Fe</i> II 78.13(1), (<i>Cr</i> II 78.10(1))
4282.74	0	<i>Fe</i> I 82.41(600), <i>Mn</i> II 82.50(3), (<i>Ca</i> I 83.01(40)), (<i>Cr</i> II 83.02(1))
4284.28	1	<i>Cr</i> II 84.21(20)
4287.79	1	<i>Ti</i> II 87.88(30)
4290.12	4	<i>Ti</i> II 90.23(60), (<i>Cr</i> I 89.72(3000))
4294.07	4	<i>Ti</i> II 94.12(80), <i>Fe</i> I 94.13(700)
4296.57	3	<i>Fe</i> II 96.57(6)
4298.78	0	<i>Fe</i> I 99.24(500), <i>Fe</i> I 98.04(100), <i>Ca</i> I 98.99(30)
4300.09	5	<i>Ti</i> II 00.05(100)
4301.99	4	<i>Ti</i> II 01.93(50)
4303.18	5	<i>Fe</i> II 03.17(8)
4305.94	1	<i>Fe</i> I 05.45(100), <i>Sc</i> II 05.71(20), <i>Sr</i> II 05.45(40)
4307.92	3	<i>Ti</i> II 07.91(100), <i>Fe</i> I 07.91(1000), (<i>Ca</i> I 07.74(45))
4309.04	0	<i>Fe</i> I 09.38(125), (<i>Cr</i> II 08.82(2))
4312.73	4	<i>Ti</i> II 12.87(100), (<i>Fe</i> II 13.03(1))
4314.55	6	<i>Fe</i> II 14.29(4), <i>Ti</i> II 14.98(100), <i>Fe</i> I 15.09(500), (<i>Sc</i> II 14.08(150))
4316.49	1	<i>Ti</i> II 16.80(35)
4319.32	0	(<i>Fe</i> II 19.72(1))
4320.86	3	<i>Ti</i> II 20.96(40), <i>Sc</i> II 20.75(40)
4325.40	5	<i>Fe</i> I 25.76(1000), (<i>Sc</i> II 25.01(40))
4330.40	3	<i>Ti</i> II 30.24(40), <i>Ti</i> II 30.71(30)
4332.58	1
4337.86	4	<i>Ti</i> II 37.92(125)
4340.57	15	<i>Hγ</i> 40.47(200)
4343.98	3n	<i>Ti</i> II 44.29(50), (<i>Cr</i> I 44.51(400)), (<i>Mn</i> II 43.99(2))
4348.20	0	<i>Al</i> II 47.78(20), (<i>Mn</i> II 48.49(1))
4351.72	8	<i>Fe</i> II 51.76(9), (<i>Mg</i> I 51.91(15))
4354.64	1	<i>Fe</i> II 54.36(2), (<i>Sc</i> II 54.61(10)), (<i>Ca</i> I 55.10(50)), (<i>La</i> II 54.44(200))
4357.63	1	<i>Fe</i> II 57.57(4)
4359.87	0	<i>Zr</i> II 59.74(10), (<i>Cr</i> I 59.63(200))
4367.86	3	<i>Ti</i> II 67.66(25), <i>Fe</i> II 68.26(1), <i>Fe</i> I 67.58(100), (<i>O</i> I 68.30(1000))
4369.50	1	<i>Fe</i> II 69.40(2), <i>Fe</i> I 69.77(200)
4374.58	3	<i>Sc</i> II 74.45(25), <i>Ti</i> II 74.82(35), <i>Y</i> II 74.95(300)
4377.48	1	<i>Mo</i> II 77.76(200)
4379.68	0	<i>Mn</i> II 79.74(1)
4384.73	6n	<i>Fe</i> II 85.38(7), <i>Fe</i> I 83.55(1000), <i>Mg</i> II 84.64(8), (<i>Fe</i> II 84.33(pred.))
4390.57	1n	<i>Ti</i> II 91.03(25), <i>Fe</i> I 90.95(100), <i>Mg</i> II 90.58(10), <i>Fe</i> II 89.40(1)
4395.06	5	<i>Ti</i> II 95.04(150)
4399.85	4	<i>Ti</i> II 99.77(100)
4404.57	1	<i>Fe</i> I 04.75(1000)
4406.72	1	(α Cygni)

TABLE 2—Continued

Wave Length	Int	Identification*
4409.32	0	<i>Ti</i> II 09.52(10), <i>Ti</i> II 09.22(8)
4411.36	2	<i>Ti</i> II 11.08(100)
4413.49	0	<i>Fe</i> II 13.60(0)
4415.20	2	<i>Fe</i> I 15.12(600), (<i>Sc</i> II 15.56(25))
4417.26	6	<i>Fe</i> II 16.82(7), <i>Ti</i> II 17.72(80)
4421.85	1n	<i>Ti</i> II 21.95(35)
4430.77	0n	<i>Fe</i> I 30.62(200), (<i>Fe</i> II 31.63(1))
4435.00	0n	<i>Ca</i> I 34.96(150), <i>Ca</i> I 35.69(100), <i>Fe</i> I 35.15(70)
4441.78	1	(<i>Fe</i> I 42.34(400)), (<i>Ti</i> II 41.72(pred.))
4443.95	5	<i>Ti</i> II 43.80(125)
4447.32	0	<i>Fe</i> I 47.72(200)
4450.34	3	<i>Ti</i> II 50.49(50)
4451.45	0	<i>Fe</i> II 51.54(4)
4455.34	1	<i>Fe</i> II 55.26(3), (<i>Ca</i> I 54.78(200))
4461.57	1	<i>Fe</i> I 61.65(300), (<i>Zr</i> II 61.22(10))
4464.39	1	<i>Ti</i> II 64.46(40)
4468.47	4	<i>Ti</i> II 68.50(150)
4470.57	1	<i>Ti</i> II 70.86(25)
4472.88	2	<i>Fe</i> II 72.92(2)
4478.47	0	(<i>Mn</i> II 78.74(1))
4481.43	2n	<i>Mg</i> II 81.33(100), <i>Fe</i> II 80.69(1)
4488.65	3	<i>Fe</i> II 89.18(4), <i>Ti</i> II 88.32(125)
4491.30	2	<i>Fe</i> II 91.40(5)
4495.26	1	(<i>Fe</i> II 95.52(pred.)), (<i>Ti</i> II 95.43(pred.))
4497.50	0	(<i>Zr</i> II 96.96(15)), (<i>Na</i> I 97.72(70))
4501.00	4	<i>Ti</i> II 01.28(100)
4508.16	5	<i>Fe</i> II 08.28(8)
4515.53	5	<i>Fe</i> II 15.34(7)
4520.20	4	<i>Fe</i> II 20.22(7)
4522.82	5	<i>Fe</i> II 22.63(9)
4524.68	0	<i>Ti</i> II 24.73(10), <i>Fe</i> I 25.15(100), <i>S</i> II 24.95(150)
4526.93	0	<i>Fe</i> II 26.58(m), <i>Ca</i> I 26.93(100)
4528.92	2	<i>Fe</i> I 28.62(600), <i>V</i> II 28.51(300)
4532.20	0	(<i>V</i> II 32.19(40))
4533.99	4	<i>Ti</i> II 33.97(150), <i>Fe</i> II 34.17(2), (<i>Mg</i> II 34.26(4))
4541.31	3n	<i>Fe</i> II 41.52(4)
4544.65	1	(<i>Ti</i> II 44.01(20)), (<i>Ti</i> II 45.14(15))
4549.57	7	<i>Fe</i> II 49.47(10), <i>Ti</i> II 49.63(200), <i>Fe</i> II 49.21(4)
4554.25	0	<i>Ba</i> II 54.04(1000), (<i>Zr</i> II 53.96(12))
4555.87	6	<i>Fe</i> II 55.89(8)
4558.69	4	<i>Cr</i> II 58.66(100), (<i>La</i> II 58.47(200))
4564.08	3n	<i>Ti</i> II 63.77(200), <i>V</i> II 64.59(200), (<i>Cr</i> II 64.27(1))
4566.88	1n	<i>Cr</i> II 65.78(10), <i>Ti</i> II 68.31(8)
4571.85	4	<i>Ti</i> II 71.98(300)
4576.72	3	<i>Fe</i> II 76.33(4)
4579.84	1	<i>Fe</i> II 80.05(1), <i>Fe</i> II 79.52(1), (<i>La</i> II 80.08(150))
4583.81	7	<i>Fe</i> II 83.83(11)
4588.36	3	<i>Cr</i> II 88.22(75), (<i>Al</i> II 48.19(30))
4591.91	1	<i>Cr</i> II 92.09(20)
4596.33	1	(<i>A</i> I 96.10(1000)), (<i>Fe</i> II 95.68(pred.))
4618.76	3nn	<i>Cr</i> II 18.83(35), <i>Cr</i> II 16.64(18), <i>Fe</i> II 20.51(3)
4629.39	5	<i>Fe</i> II 29.34(7), (<i>Ti</i> II 29.33(8))
4634.61	3n	<i>Fe</i> II 35.33(5), <i>Cr</i> II 34.11(25)
4649.35	0	(<i>Fe</i> II 48.93(0))
4657.05	2	<i>Fe</i> II 56.97(1), <i>Ti</i> II 57.21(18)
4666.43	1	<i>Fe</i> II 66.75(2)
4670.61	0	<i>Sc</i> II 70.40(300), (<i>Fe</i> II 70.17(0))
4675.51	1

strong, relative to α Cygni, while Fe II and Cr II were strong and Ti II and Mn II were very weak. In 1941 all lines had become stronger, but Ti II and Ca II had become greatly strengthened, while Fe II and Ni II had not changed very greatly, so that by the end of 1941 the only marked difference between the metallic spectrum of Pleione and that of α Cygni (other than differences caused by dilution) was the weakness of Mn II in Pleione. In the last 14 months the lines of Mn II have also greatly increased in intensity, so that at the present time all these lines closely resemble those of α Cygni. The relevant ionization and excitation potentials of these elements are shown in the accompanying table.

Element	<i>Ni</i>	<i>Fe</i>	<i>Cr</i>	<i>Ti</i>	<i>Mn</i>
First ionization potential.	7.6	7.8	6.7	6.8	7.4
Second ionization potential.	18.2	16.5	16.6	13.6	15.7
Exciting potential.	3	3	3	1	2

The ionization potential of Mn^+ is intermediate between those of Ti^+ and Fe^+ , and so are the relevant lower-excitation potentials. The exceptionally late strengthening of Mn II cannot be explained in terms of ordinary excitation or ionization. We are concerned here with a most puzzling question, the solution of which probably must be sought in the specific mechanism of line excitation which operates in each of these ions. The lower levels of all lines are metastable, and it is almost certain that the atoms in the shell reach these levels only by first absorbing some resonance line and then emitting a line of longer wave length, thus leaving the atom in the required metastable level. The populations in the metastable levels will, therefore, depend upon various factors, such as the transition probabilities for the resonance and excited lines, which are not sufficiently known at the present time.

4. The central intensities of the sharp H cores in Pleione are deeper than in α Cygni, in spite of the fact that the equivalent widths of the lines in α Cygni are greater than those of the cores in Pleione. This remarkable property is shared by nearly all shells. Figure 5 shows a tracing of $H\delta$ on a recent plate of Pleione. The intensity of the line in the center corresponds to 14 per cent of the continuous spectrum. Correction for finite resolving-power should bring this value to about 10 per cent. This is in marked contrast to the central intensity of $H\delta$ in α Cygni: 22 per cent, as determined by E. G. Williams,³ or 35 per cent, as determined by S. Günther.⁴ Roughly speaking, we can assume that the intensity of the line center in Pleione is one-half or one-third of that of α Cygni.

The interpretation of this phenomenon has an important bearing upon the theory of central line intensities. Following the procedure of Unsöld,⁵ which he has recently justified in his discussion of the spectrum of τ Scorpii,⁶ the central intensity of $H\delta$ is attributed to thermal re-emission in the frequency of a line formed by pure absorption. In such a case the central intensity is independent of the oscillator strength of the line and is produced solely by the transfer mechanism of the radiation. The central intensity corresponds to the intensity of the continuous spectrum of the limb of the star—exactly as had first been shown in Schwarzschild's theory of stellar absorption lines.

The small central intensities in Pleione (and in other shells) must be due to the effect of dilution. The solid angle subtended by the disk of the star from a point in the shell is

$$W = \frac{R^2}{4r^2}.$$

³ *Ann. Solar Phys. Obs., Cambridge*, 2, Part II, 1932.

⁴ *Zs. f. Ap.*, 7, 106, 1933.

⁵ *Physik der Sternatmosphären*, p. 301, Berlin, 1938.

⁶ *Zs. f. Ap.*, 21, 1941, available to us only in the form of advance proofs.

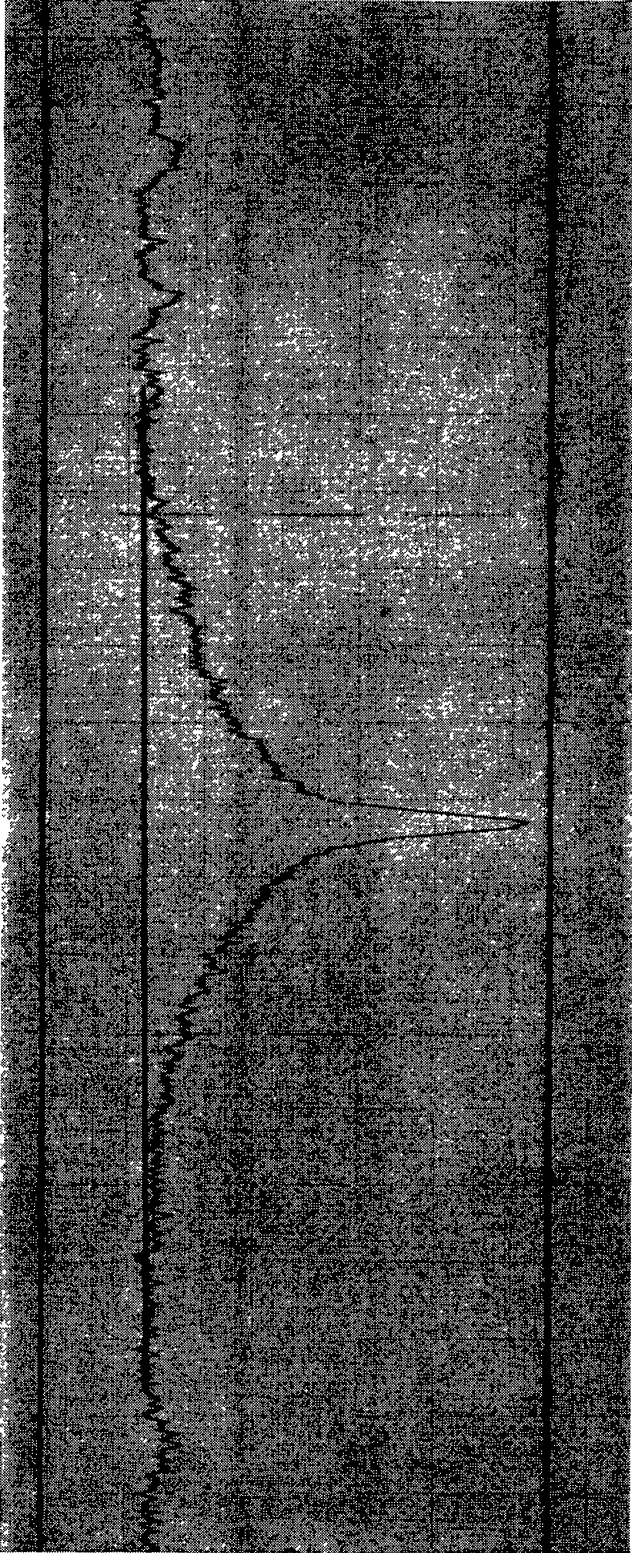


FIG. 5.—Tracing of $H\delta$ in Pleione (January 30, 1943). The three straight lines designate total darkness, continuous spectrum, and clear film. The distance between the continuous spectrum and the bottom of the line corresponds to a ratio of 1:0.14 in the intensities.

Hence the re-emission in the equation of transfer must be multiplied by the factor W . The problem is somewhat complicated, because we expect that in the shell Rosseland cycles will be operating, whose effect will be to increase the line-emission relative to the absorption. It is premature to try to estimate this effect. The best that we can do is to introduce a factor f such that, if n' is the ratio of the number of atoms in the upper state to the number in the lower state and n is the corresponding ratio in thermodynamic equilibrium at the temperature concerned, then

$$f = \frac{n'}{n} \geq 1.$$

If we make use of Eddington's⁷ designations, we can write the equation of transfer in the following form:

$$\cos \theta \frac{dJ'_\nu(\theta)}{\rho dr} = -(k+l)J'_\nu(\theta) + W(k+fl)J_\tau.$$

The solution follows closely Eddington's procedure. We introduce the optical depth

$$\tau = -\int k \rho dr$$

and reduce the equation to Eddington's formula (50). If $\eta = l/k$, we find that the central intensity of a line H'_ν/H is increased over the corresponding value in thermodynamic equilibrium by the factor

$$g = \frac{W(1+f\eta)}{1+\eta}.$$

The observed values are

$$g = 0.3, \quad W = 0.1.$$

This would give an equation for f . But it should be remembered that with a constant value of k it is impossible to find lines produced by pure absorption which have smaller central intensities than 50 per cent, when $W = 1$ and $f = 1$. In order to account for the observed central intensities, Unsöld discusses the variation of k with wave length and determines for τ Scorpii the ratio \bar{k}/k . Hence it is meaningless to pursue this matter further, beyond concluding that the small central intensity in Pleione is caused by the factor W and that probably the full effect of this factor is checked by the opposite trend of the factor f . It seems plausible that this factor should be considerably smaller than $1/W$.

The duplicity and appreciable over-all width of the bright H lines shows that the shell is rotating with a fairly large velocity (~ 100 km/sec). Hence the emission from those parts of the shell which are not seen projected upon the apparent disk of the star are not superposed over the central intensities of the sharp absorption lines. Hence our treatment, neglecting this emission, was correct.

5. An inspection of Plates I and II shows that the metallic lines of Pleione are less weakened by continuous Balmer absorption than in α Cygni. This is a conspicuous phenomenon, apparently shared by some other shells (14 Comae). It is especially pronounced in the immediate vicinity of the Balmer limit, where the lines of Pleione on recent plates have much greater intensities than in α Cygni. The entire group of lines between Ti II 3641 and Ti II 3659 is much stronger in Pleione. To the red of the Balmer limit, λ 3647, this is probably in part due to the extreme sharpness of the lines of Pleione. Only when, for example, in the case of H 30 the wave length, λ 3612.26, agrees closely

⁷ *M.N.*, 89, 620, 1929.

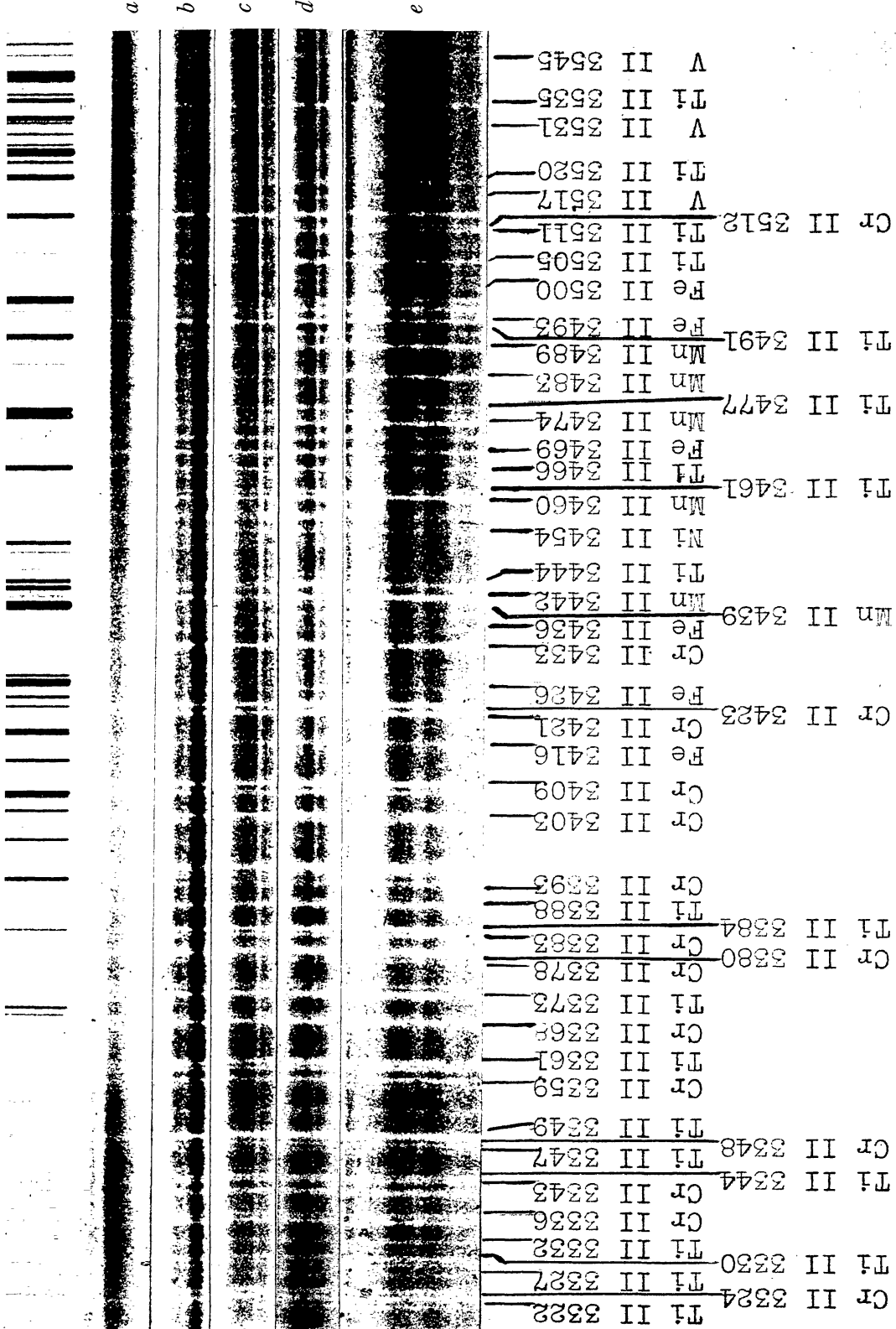
with $Ti\ II\ 3662.24$, the metallic line is effectively suppressed. Perhaps the effect of the wings in $\alpha\ Cygni$ is more pronounced than had been considered probable in the past, and it is just possible that it may extend several angstrom units to the violet of $\lambda\ 3647$. This suggests an explanation of the strange phenomenon found by Struve and Sherman,⁸ and emphasized by Greenstein,⁹ that the weakening of metallic lines on the violet side of $\lambda\ 3647$ is more strongly correlated with distance to the limit than is compatible with the ν^3 factor in the continuous absorption coefficient.

The general absence of weakening of the metallic lines by the Balmer continuum of Pleione may be attributed to the semitransparency of the shell. The observed weakening in $\alpha\ Cygni$ and other A-type stars is due to the great optical depth of the reversing layer. The shell of Pleione can have only a relatively small optical depth, because photometric observations by Mündler¹⁰ have shown only a small increase in brightness from 1939 to 1942, corresponding to less than 0.2 mag.

⁸ *Ap. J.*, **91**, 428, 1940.

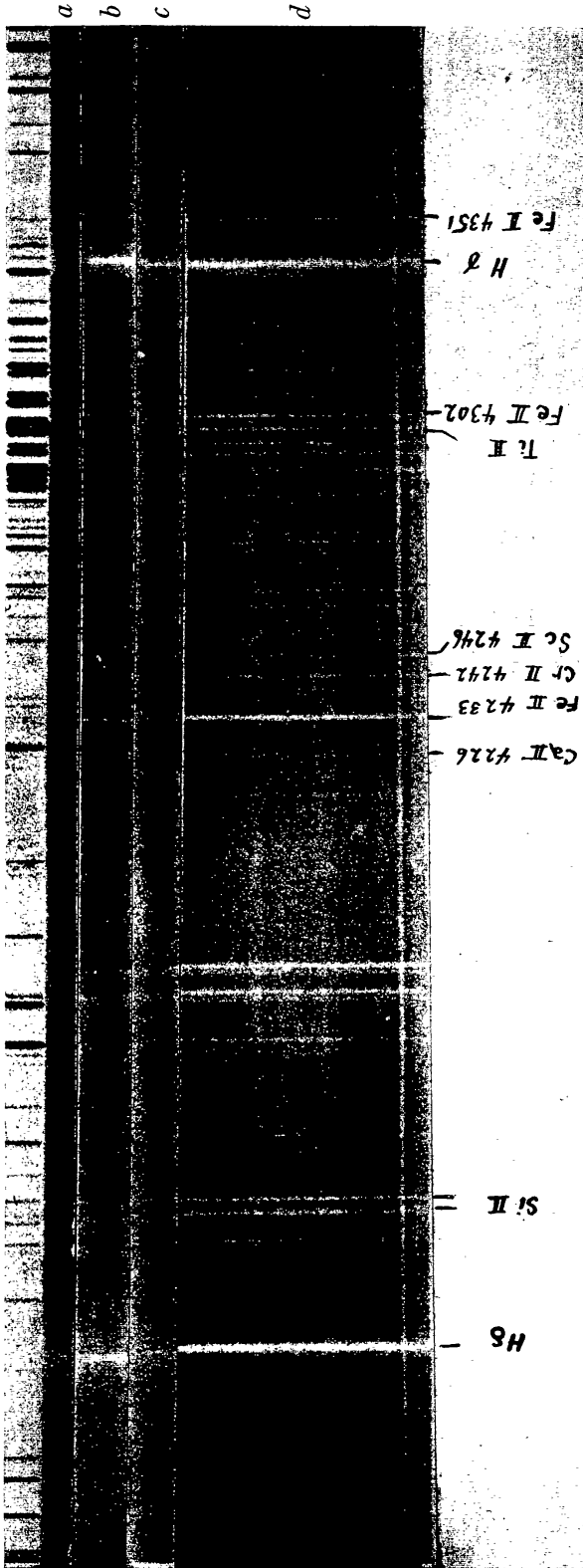
⁹ *Pub. A.A.S.*, **10**, 295, 1942.

¹⁰ *Beob. Zirk. d. A.N.*, **24**, No. 12, 1942.



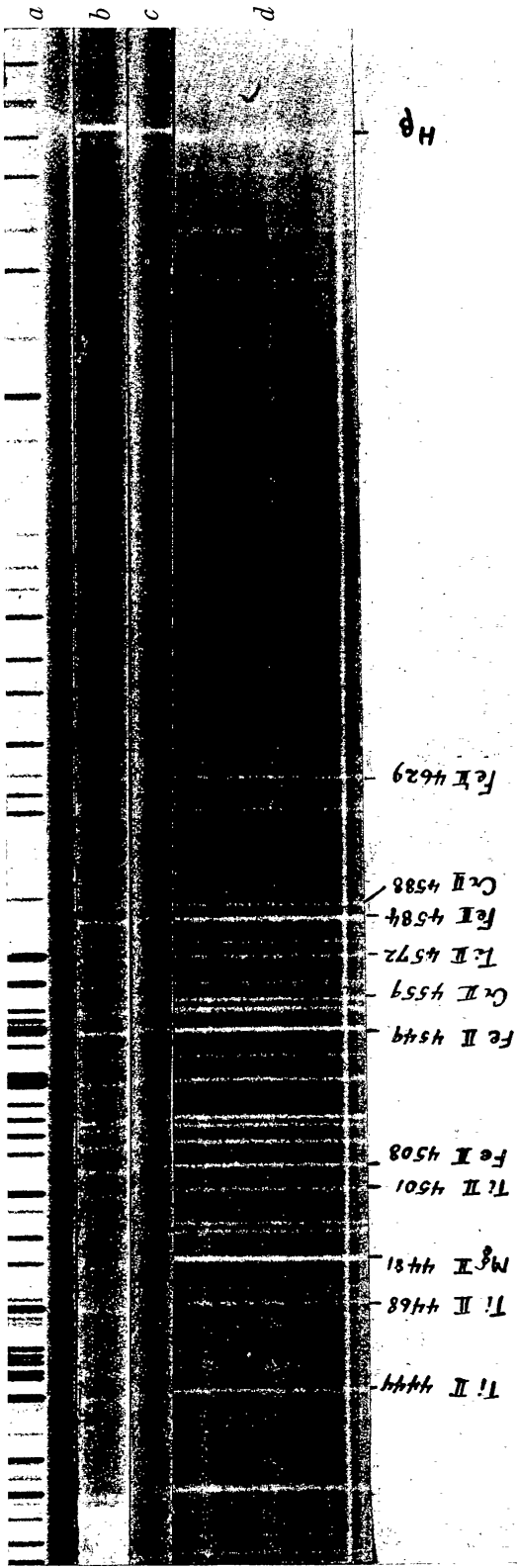
SPECTRUM OF PLEIONE, REGION λ 3320-3550
 (a) Pleione, Nov. 12, 1940; (b) Pleione, Nov. 2, 1941; (c) Pleione, Jan. 8, 1942; (d) Pleione, Nov. 25, 1942; (e) α Cygni

PLATE XXXV



SPECTRUM OF PLEIONE, VIOLET REGION
 (a) Pleione, 1906; (b) Pleione, Nov. 1941; (c) Pleione, 1940; (d) α Cygni

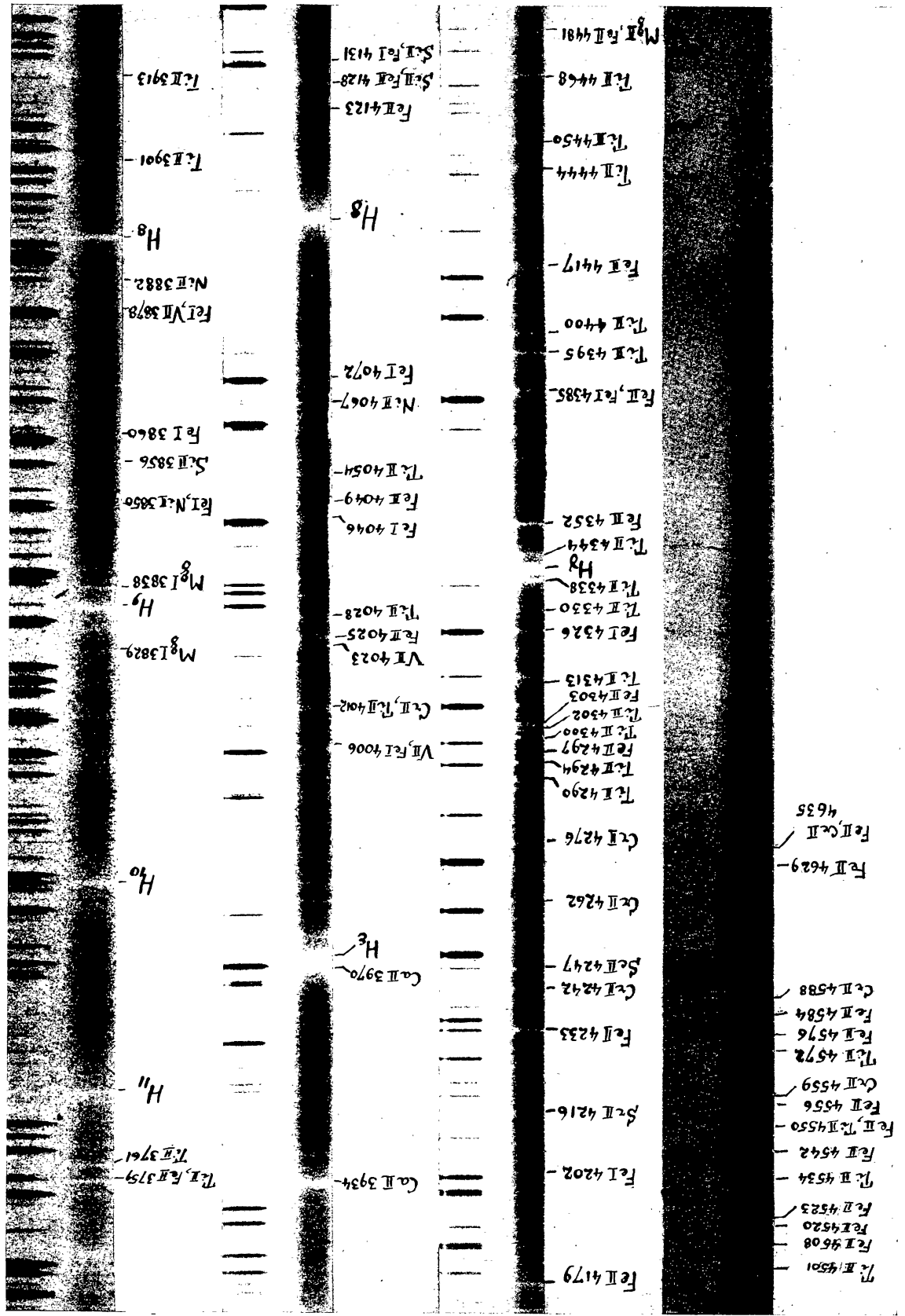
PLATE XXXVI



SPECTRUM OF PLEIONE, BLUE REGION

(a) Pleione, 1906; (b) Pleione, Nov., 1941, (c) Pleione, 1940; (d) α Cygni

PLATE XXXVII



SPECTRUM OF PLEIONE, JANUARY 30, 1943, REGION λ 3750-4700