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Chemical composition of the atmosphere of β Lyrae

By

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With 8 Figures in the Text

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A quantitative analysis of β Lyrae has been made for deciding if this star is hydrogen-deficient as some observers have suggested, and if it has other abundance peculiarities. The degree of excitation of the FeII lines, and the ionization equilibria of FeI and FeII, and of SiII and SiIII indicate that the temperature that should be used for the determination of the total abundances ranges between 13400° K and 12000° K. The main abundance peculiarities are the following: He/H = 2.25 (for $\Theta = 0.41$) or He/H = 1.0 (for $\Theta = 0.38$). The ratio He/Fe is between 2.5×10^4 and 5×10^3, according to the assumed helium excitation temperature, $\Theta = 0.41$ or $\Theta = 0.38$ respectively. Moreover nitrogen, magnesium and sulphur are in excess; among the heavier elements scandium, iron and strontium are in excess by a factor of the order of ten, while silicon and titanium are almost normal with respect to standard stars.

1. Introduction

The eclipsing binary β Lyrae has been studied by several authors both photometrically and spectroscopically. An extensive list of references has been made by STRUVE (1958) and by SAHADE et al. (1959). Several models have been proposed for this system, and until a few years ago it was generally accepted that the primary, of spectral type B8 or B9, was the more massive, and the secondary, whose spectrum is never observable, was the less massive. The recent discussion by ABT et al. (1962) gave for the system a probable distance of the order of 260 parsecs. Several other arguments prove that the distance cannot be much greater than 260 parsecs. The consequences of this recent distance determination are discussed by WOOLF (1965). From the distance the dimensions of the primary can be derived; it follows that $a_1 \sin i$ is considerably larger than the radius of the primary. But since the light curve shows that the two stars are almost in contact, if the secondary is a normal ellipsoid, it must have a surface area four times greater than the primary and therefore the secondary should be more luminous than the primary, which is in strong disagreement with the observations. This paradox has been resolved by the model proposed by HUANG (1963). According to his model the secondary is a disk with a star at its center; the primary is the

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less massive component ($\mathfrak{M} \sim 2\mathfrak{M}_\odot$) while the secondary has a mass $\mathfrak{M} \sim 11.7\mathfrak{M}_\odot$. The underluminosity of the secondary is explicable if we assume that at least half of the mass is contained in the disk which radiates little because it can only generate a small central pressure by collapse in one dimension.

Even though there have been many papers on β Lyrae, the problem of its chemical composition has been considered only by BOYARCHUK (1959) who found β Lyrae to be strongly hydrogen-deficient. Measurements of line intensities have been published by STRUVE and ZEBERGS (1961) and compared with the line intensities of some standard stars of spectral type B and A. Although these authors did not make a complete quantitative analysis of β Lyrae, they estimated that it should have some composition peculiarities, the lines of Fe II being strong like those of the A-type stars and the He lines being of the same strength of those of the B2-type stars.

BOYARCHUK finds that β Lyrae has a H/He ratio about 200 times smaller than that of the comparison stars. From a quantitative analysis of the hydrogen-poor star v SAGITTARII, HACK and PASINETTI (1963) found too that the H/He ratio is 200 times smaller than that for the normal stars. However the general aspect of the spectrum of β Lyrae, compared with that of v Sagittarii, is very different and much closer to normality. Moreover the Balmer discontinuity has a value which is normal for the spectral type of β Lyrae. In the spectrum of v Sagittarii, on the contrary, the discontinuity is not visible at all.

For this reason we have decided to make another quantitative analysis of β Lyrae, using the measurements of STRUVE and ZEBERGS, who used grating spectrograms of dispersion 10 A/mm covering the spectral region $\lambda\lambda$ 3814—4584, and studying a series of grating spectrograms which we took at the Merate Observatory with dispersion 22 A/mm (in the third order) and 35 A/mm (in the second order) covering the spectral region $\lambda\lambda$ 3400—6700.

2. The observations

Table 1 gives the list of the spectrograms, the date and the phase, computed by the Prager formula (1931), corrected by SAIDOV (1955) and adopted by STRUVE (1958):

Epoch of prim. min. $=$ J.D. $2398590.57 + 12.908006\,\mathrm{E} + 0.3919 \times \times 10^{-5}\,\mathrm{E}^2 - 0.3 \times 10^{-10}\,\mathrm{E}^3$.

For checking the phase, several spectrograms taken during different cycles have been measured for radial velocity. We have used only the Si II lines in the violet region of the spectrum, because these are the only lines which are not affected by contribution of the shell. The velocities which we have measured are given in Fig. 1 and for comparison we show

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Table 1. *The observations*

Spectrogram	Date	U.T.	Phase	Spectral range
Fa 1184	July 16, 1962	23^h15^m	3039.701	3300—4600 (II order)
Fa 1185	July 16, 1962	23 20	3039.702	,,
Fa 1195	July 18, 1962	21 27	3039.850	,,
Fa 1196	July 18, 1962	21 34	3039.851	,,
Fa 1206	July 19, 1962	21 35	3039.928	,,
Fa 1207	July 19, 1962	21 45	3039.929	,,
Fa 1725	July 2, 1963	20 35	3066.836	,,
Fa 1726	July 2, 1963	20 43	3066.837	,,
Fa 1728	July 2, 1963	22 15	3066.839	,,
Fa 1197	July 18, 1962	21 50	3039.851	4500—5800 (II order)
Fa 1198	July 18, 1962	22 05	3039.852	,,
Fa 1208	July 19, 1962	21 55	3039.929	,,
H 1682	May 6, 1963	0 40	3062.363	,,
H 1683	May 6, 1963	1 5	3062.305	,,
FaJ 1706	June 13, 1963	0 10	3065.300	,,
FaJ 1707	June 13, 1963	0 35	3065.302	,,
Fa 1729	July 2, 1963	21 50	3066.840	,,
Fa 1730	July 2, 1963	22 25	3066.843	,,
K 1807	August 23, 1963	23 13	3070.944	,,
K 1813	August 26, 1963	22 25	3071.174	,,
Fa 1188	July 17, 1962	0 35	3039.705	5700—7000 (II order)
Fa 1199	July 18, 1962	22 35	3039.854	,,
Fa 1209	July 19, 1962	22 22	3039.931	,,
Fa 1280	August 14, 1962	20 25	3041.935	,,
Fa 1456	Sept. 19, 1962	18 57	3044.714	,,
Fa 1460	Sept. 20, 1962	18 40	3044.790	,,
FaJ 1748	July 6, 1963	20 15	3067.145	,,
JK 1786	August 2, 1963	23 25	3069.322	,,
K 1808	August 23, 1963	23 37	3070.945	,,
K 1814	August 27, 1963	24 00	3071.253	,,
H 1132	June 10, 1962	0 40	3036.786	3500—4400 (III order)
G 1133	June 10, 1962	21 45	3036.854	,,
Fa 1137	June 17, 1962	0 22	3037.384	,,
P 1149	June 19, 1962	23 15	3037.613	,,
Fa 1152	June 21, 1962	22 15	3037.764	,,
K 1155	June 22, 1962	22 18	3037.842	,,
Fa 1181	July 16, 1962	22 30	3039.698	,,
Fa 1182	July 16, 1962	22 40	3039.699	,,
Fa 1183	July 16, 1962	22 55	3039.700	,,
Fa 1205	July 19, 1962	21 15	3039.927	,,
G 1215	July 21, 1962	23 35	3040.010	,,
K 1217	July 22, 1962	21 15	3040.079	,,
G 1225	August 8, 1962	23 25	3041.480	,,
G 1228	August 9, 1962	22 59	3041.556	,,
G 1232	August 10, 1962	19 47	3041.621	,,
Fa 1242	August 11, 1962	22 34	3041.707	,,
Fa 1243	August 11, 1962	22 42	3041.708	,,
Fa 1253	August 12, 1962	20 34	3041.780	,,
Fa 1254	August 12, 1962	20 46	3041.781	,,

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Table 1. (Continuation)

Spectrogram	Date	U.T.	Phase	Spectral range
Fa 1263	August 13, 1962	19h45m	3041.855	3500—4400 (III Order)
Fa 1264	August 13, 1962	19 52	3041.856	,,
Fa 1281	August 14, 1962	20 57	3041.937	,,
Fa 1282	August 14, 1962	21 10	3041.937	,,
K 1287	August 15, 1962	22 26	3042.019	,,
K 1293	August 16, 1962	22 32	3042.098	,,
K 1294	August 18, 1962	20 18	3042.244	,,
K 1302	August 19, 1962	20 30	3042.322	,,
P 1319	Sept. 11, 1962	20 41	3044.102	,,
P 1325	Sept. 12, 1962	18 45	3044.173	,,
P 1332	Sept. 13, 1962	18 56	3044.251	,,
K 1437	Sept. 14, 1962	19 00	3044.329	,,
Fa 1446	Sept. 18, 1962	18 35	3044.635	,,
Fa 1447	Sept. 18, 1962	18 40	3044.635	,,
FaJ 1667	April 12, 1963	3 22	3060.513	,,

Observers: Fa, R. Faraggiana; G, A. Gökgöz; H, M. Hack; J, F. Job; K, I. Kendir; P, L. Pasinetti.

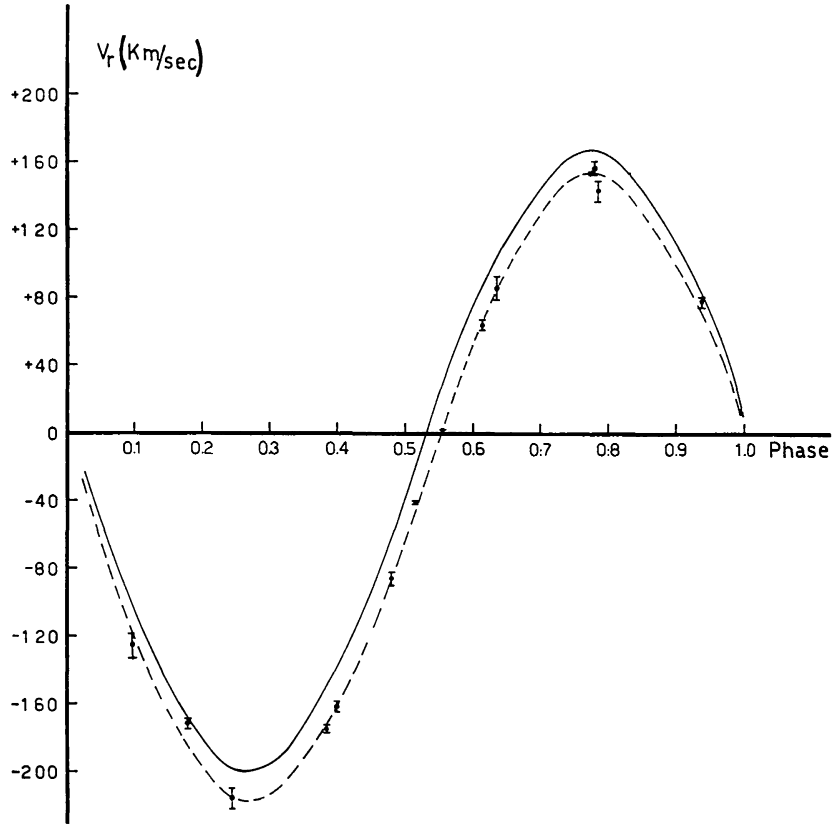

Fig. 1. Radial velocity curve derived by the SiII lines. The full line represents the observations by Sahade et al.

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Table 2. *Identifications and average equivalent widths*

λ	Element and multiplet	$-\log \frac{W_\lambda}{\lambda}$	λ	Element and multiplet	$-\log \frac{W_\lambda}{\lambda}$
3691.557	H 18	3.87	5957.612	(4)	4.79
3697.154	H 17	3.69	5978.970	(4)	4.61
3711.973	H 15	3.41	6347.091	(2)	4.37
3721.940	H 14	3.30	6371.359	(2)	4.38
3734.370	H 13	3.25	3933.664	Ca II (1)	3.80
3750.154	H 12	3.18	4246.83	Sc II (7)	4.48
3770.632	H 11	3.14	3741.633	Ti II (72)	4.57
3797.900	H 10	3.09	3757.684	(72)	4.70
3835.386	H 9	3.02	3759.291	(13)	4.16
3970.074	H ε	3.13	3761.320	(13)	4.24
4101.737	H δ	3.18	3900.546	(34)	4.33
4340.468	H γ	3.24	3913.464	(34)	4.23
3784.886	He I (64)	3.95	4294.101	(20)	4.28
3805.765	(63)	4.12	4300.052	(41)	4.32
$3819.^{606}_{761}$	(22)	3.82		(bl. Ti II)	
			3865.59	Cr II (167)	4.71
$3867.^{477}_{631}$	(20)	4.10	3979.51	(183)	4.27
			4038.03	(194)	4.65
3871.819	(60)	3.82	4242.38	(31)	4.44
3878.180	(59)	4.30	4261.92	(31)	4.60
3926.530	(58)	3.84	3814.121	Fe II (153)	4.66
4009.270	(55)	3.64	3935.942	(173)	4.32
$4026.^{189}_{362}$	(18)	3.72	4061.70	(189)	4.60
			4087.27	(28)	4.65
$4120.^{812}_{993}$	(16)	4.26	4122.638	(28)	4.72
			4173.450	(27)	4.15
4143.759	(53)	3.74	4178.855	(28)	4.23
4168.971	(52)	4.35	4233.167	(27)	4.09
4387.928	(51)	4.24	4258.155	(28)	4.63
4437.549	(50)	4.45	4273.317	(27)	4.53
5047.736	(47)	4.45	4296.567	(28)	4.42
3994.996	N II (12)	4.42	4303.166	(27)	4.27
4241.787	(47—48)	4.77	4351.764	(27)	4.23
	(bl. Cr II)		4416.817	(27)	4.57
3848.24	Mg II (5)	4.57	4508.283	(38)	4.37
	(bl. Ni II)		4515.337	(37)	4.52
4384.643	(10)	4.20	4522.634	(38)	4.55
4390.585	(10)	4.51	4541.523	(38)	4.03
$4481.^{327}_{129}$	(4)	4.07	4555.890	(37)	4.42
			4576.331	(38)	4.56
3853.657	Si II (1)	4.08	4923.921	(42)	4.60
3856.021	(1)	3.99	5018.434	(42)	4.43
3862.592	(1)	4.02	5169.030	(42)	4.19
4128.053	(3)	4.06	3849.58	Ni II (11)	4.03
4130.884	(3)	4.03	4015.50	(12)	4.49
5041.063	(5)	4.43	4067.051	(11)	4.34
$5056.^{020}_{353}$	(5)	4.31	4215.524	Sr II (1)	4.46

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also the curve derived by SAHADE et al. A systematic difference of 10 km/sec between the two curves has been found, which is probably of instrumental origin.

The measurement of equivalent widths is rather difficult,because the stellar lines are often blended with the shell lines, both in absorption and in emission. For this reason BOYARCHUK and STRUVE used only spectra taken at the phases 0.5 P, because at this phase the shell contribution is minimum. We measured not only the spectrograms at phases 0.5 P but also those at phases 0.25 P and 0.75 P, because — due to the orbital motion — at these phases the contribution of the shell affects respectively the red wing or the violet wing of each stellar line, and therefore the violet semi-contour or the red semi-contour respectively is purely stellar. Hence we measured the full contour at phase 0.5 P, and the violet (red) semi-contour at phase 0.25 P (0.75 P) and derived the total intensity multiplying by 2.

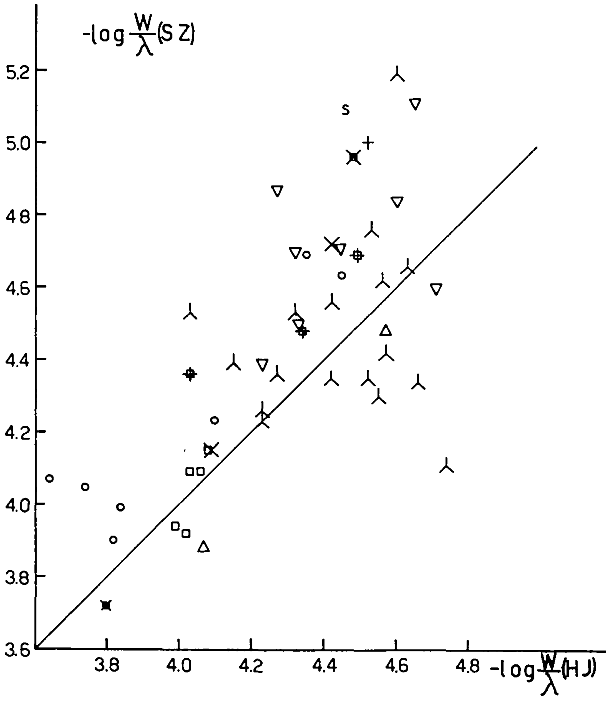

Fig. 2. Comparison of the equivalent widths measured by us and by STRUVE and ZEBERGS. ○ HeI; × NII; △ MgII; □ SiII; ✶ CaII; ⊠ ScII; ▽ TiII; ▼ CrII; + FeI; ⅄ FeII; ⊞ NiII; S SrII.

Table 2 gives the identifications and the average equivalent widths for all the phases. Variations of intensity from one phase to another are not evident; the differences appear to be random and in the order of the observational errors.

Fig. 2 gives the comparison of our equivalent widths with those measured by STRUVE and ZEBERGS. With a few exceptions, the agreement is satisfactory. Fig. 3 shows that the differences between the two

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series of measurements is strongly dependent upon wave length, suggesting that the main reason for the difference is the criterion adopted for tracing the continuum, ours being considerably higher around λ 4050, since we find systematically higher values for the total intensities.

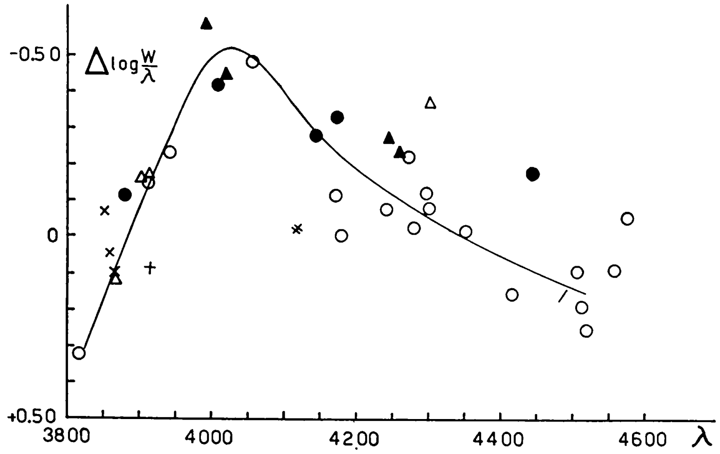

Fig. 3. log $\frac{W}{\lambda}$ (SZ) — log $\frac{W}{\lambda}$ (HJ) (indicated with $\Delta \log \frac{W}{\lambda}$) versus λ. ● HeI: / MgII; × SiII; + CaII, △ TiII; ▲ CrII; ○ FeII

3. Comparison with α Cygni and the hydrogen-poor stars υ Sagittarii and BD + 10°2179

The spectrum of β Lyrae has been compared with that of α Cygni (Fig. 4) studied by Groth (1961) and with those of the hydrogen-poor

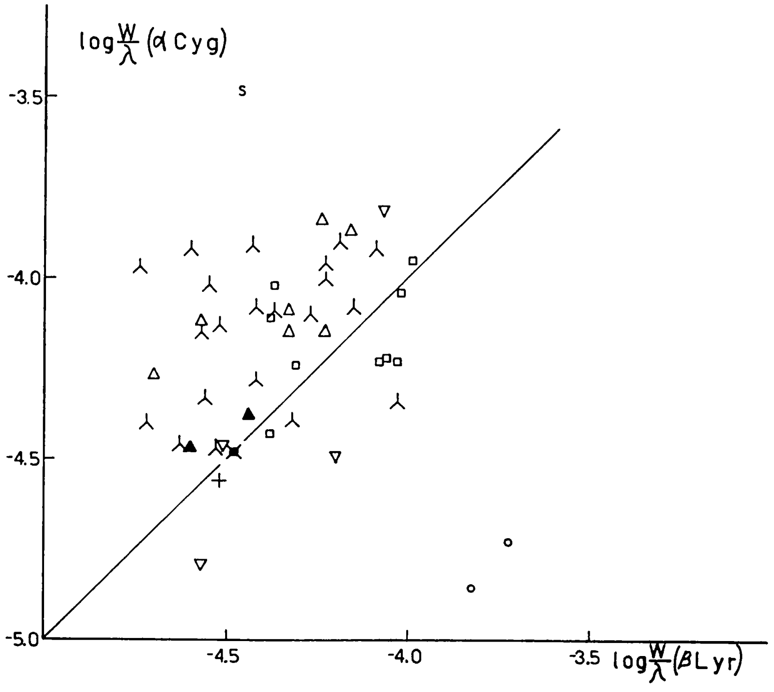

Fig. 4. Comparison of the equivalent widths for α Cyg and β Lyr. ○ HeI; ▽ MgII; □ SiII; ⊠ ScII; △ TiII; ▲CrII; + FeI; ⅄ FeII; S SrII

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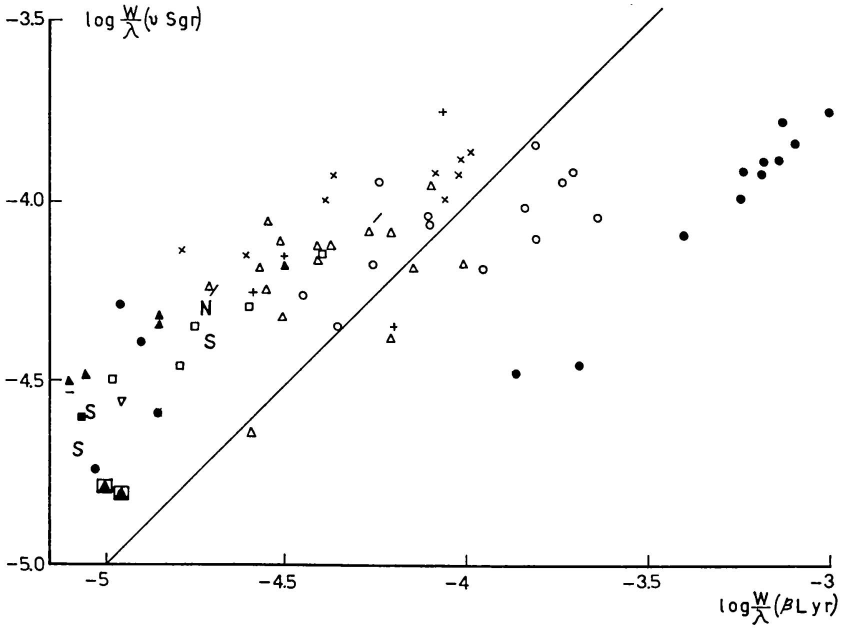

Fig. 5. Comparison of the equivalent widths for *υ* Sgr and *β* Lyr. ● HI; ○ HeI; S SII; N NII; + MgII; × SiII; ⊗ SiIII; ▽ ScII; □ TiII; ■ VII; ▲ CrII; ▲ (im Quadrat) FeI; △ FeII; △ (im Kreis) FeIII; / NiII; — SrII

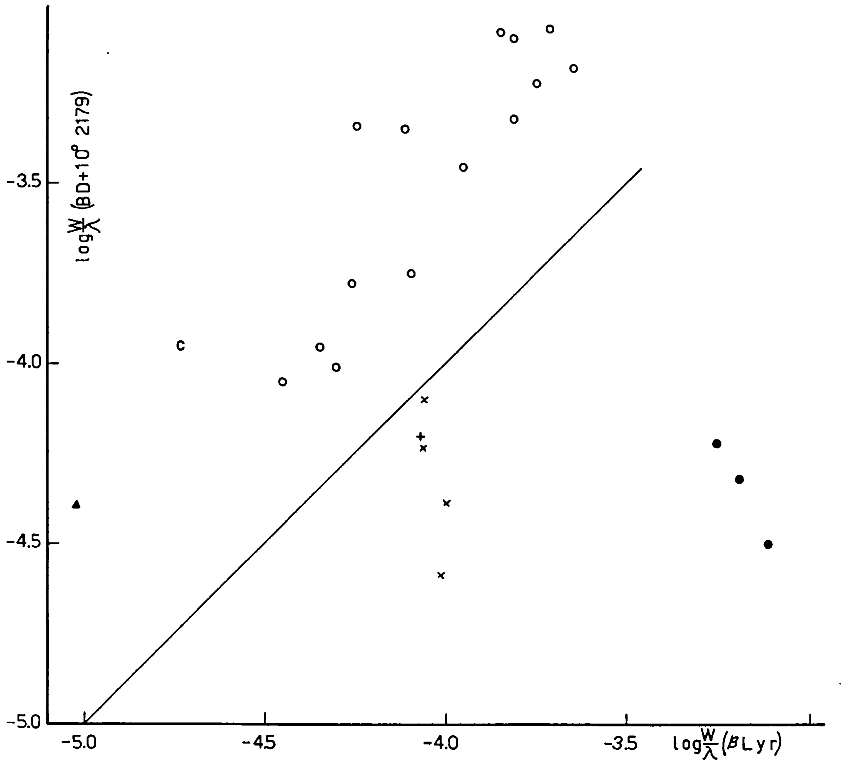

Fig. 6. Comparison of the equivalent widths for BD + 10° 2179 and *β* Lyr. ● HI; ○ HeI; C CII; + MgII; × SiII; ▲ SiIII

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stars v Sagittarii (Fig. 5) and BD + 10°2179 (Fig. 6) studied by KLEMOLA (1961). From the three graphs, the following qualitative results can be derived. Comparison with α Cygni: the HeI lines are much stronger in β Lyrae. The SiII, MgII, TiII, CrII, FeI lines are about equally intense in both stars, the FeII lines are stronger and the SrII lines much stronger in α Cygni. From this we can infer that β Lyrae is slightly hotter and denser than α Cygni. Probably helium is in excess in β Lyrae. Comparison with v Sagittarii: the Balmer lines are much stronger in β Lyrae, and the HeI lines are of almost the same strength, SiII and SiIII are both stronger, and by about the same amount in v Sagittarii, and the same is true for FeI, FeII, FeIII and for all the other elements. We infer that the temperature and the degree of ionization are about the same in the two atmospheres, but that of v Sagittarii is much more transparent because of the deficiency of hydrogen. Helium appears to be comparatively more abundant in β Lyrae.

From the comparison with BD + 10°2179 we can infer only that this star is much hotter than β Lyrae.

4. The abundance of hydrogen and helium

The determination of the abundances for hydrogen and helium is strongly affected by the uncertainty of the temperature. We can use the excitation or the ionization temperature derived from the metallic lines, or the color temperature. We can safely assume that β Lyrae is later than B3 and earlier than A2, and therefore the value of its temperature is certainly between $\Theta = 0.32$ and 0.55. The Balmer discontinuity measured in several spectra (Table 3) is on the average $D = 0.26 \pm 0.03$. The visual absolute magnitude derived for a distance of 260 parsecs is $M_v = -3.40$. Hence the more probable classification following from these two values is B8 II (HACK, 1953). Now the color B—V for an unreddened star of spectral type B8 is equal to —0.09. If we use the empirical relation given by SARGENT (1964) between color B—V and ionization temperature

Table 3. *Measurements of the Balmer discontinuity*

Spectrogram	D	Spectrogram	D
Fa 1152	0.25	Fa 1242	0.19
Fa 1181	0.18	Fa 1243	0.23
Fa 1182	0.15	K 1302	0.32
Fa 1183	0.23	P 1332	0.24
G 1225	0.24	K 1437	0.17
G 1228	0.43		

Average value: $D = 0.26 \pm 0.03$.

$$\Theta_{\mathrm{ion}} = \mathrm{B-V} + 0.50$$

we derive for β Lyrae $\Theta_{\mathrm{ion}} = 0.41$.

We shall discuss again which is the more probable value to adopt for the temperature, on the basis of the results given by the metallic lines.

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For the moment we compute the number of neutral hydrogen atoms in the second state of excitation, the number of neutral helium atoms in the excited state 2^3P, and the electron density.

The number of neutral atoms of hydrogen in the second state of excitation has been computed by means of the Minnaert formula. If we assumed for the central depth the measured value $R_c = 0.50$ (Table 4) we find $\log N_{0,2}H = 17.52$. But since probably there is a central emission component, we prefer to assume $R_c = 0.60$, i.e. the mean value of the central depth for the Balmer lines derived for the B8-type stars (HACK, 1959). It follows that $\log N_{0,2}H = 17.10$, which we assume as the more probable value.

Table 4. *Central depth of the Balmer lines*

Line	R_c	Line	R_b
Hγ	0.35	H13	0.46
Hδ	0.43	H14	0.45
Hε	0.42	H15	0.42
H9	0.53	H16	0.35
H10	0.51	H17	0.29
H11	0.49	H18	0.27
H12	0.49		

From the Inglis and Teller formula, since the quantum number of the last visible line is $n = 22$ it follows for the electron density $\log N_e = 13.18$. From the Holtsmark relation we find $\log N_e = 12.79$ (from Hγ) and $\log N_e = 12.93$ (from Hδ). We assume as the more probable value $\log N_e = 13.0$ and $\log P_e \sim 1.25$.

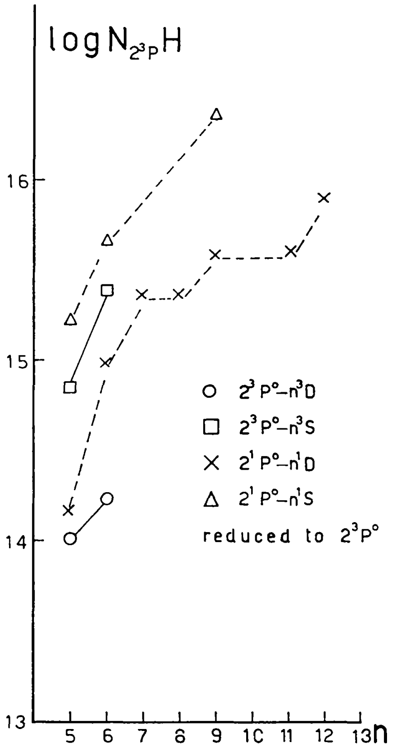

Fig. 7. Determination of the abundance of helium

For the number of atoms of He I, using the Unsöld method, we find $\log N_{2^3P}H \geqq 16.5$.

The analogous quantities derived by BOYARCHUK are the following: $\log N_{0,2}H \geqq$ $\geqq 15.90$. The strong disagreement with our results is due to the fact that BOYARCHUK derives only a lower limit for the number of hydrogen atoms using the Unsöld method for a thin layer; our corresponding value by the same method is 16.10. For the electron density he derives $\log N_e = 13.15$ in good agreement with our value. For helium he gives $\log N_{2^3P}H \geqq 15.40$ which disagrees with our results; the reason for this is that BOYARCHUK has not measured the line λ 3878 which gives the higher value for $\log N_{2^3P}H$ (Fig. 7).

From the Boltzmann and Saha relations we compute the total number of hydrogen and helium atoms for several values of the temperature. It is obviously important to derive a reasonable value for T, otherwise the determination of the abundance of hydrogen and helium

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is meaningless. However it appears that for values of Θ in the range 0.45 to 0.35 where the values for β Lyrae is very probably included, the ratio He/H varies from 25 to 1/1.55, i.e. values higher than those found in normal stars (He/H for normal stars = 1/6).

5. The abundances of the other elements

A curve of growth has been constructed using the lines of Fe II in different excited states. The minimum dispersion around the curve of growth has been found assuming $\Theta_{\text{exc}} = 0.42$. The vertical shift of the empirical curve with respect to the theoretical curve gives for the component v of the thermal and turbulent velocities $v = 6$ km/sec. From the comparison of the curve of growth of β Lyrae with that of α Cygni constructed using the data given by GROTH, with $\Theta_{\text{exc}} = 0.55$, we find $\log(N/\varkappa)_\beta - \log(N/\varkappa)_\alpha = -0.55$ for Fe II (Fig. 8). The comparison of the curves of growth for the other metals with that for Fe II gives the following results:

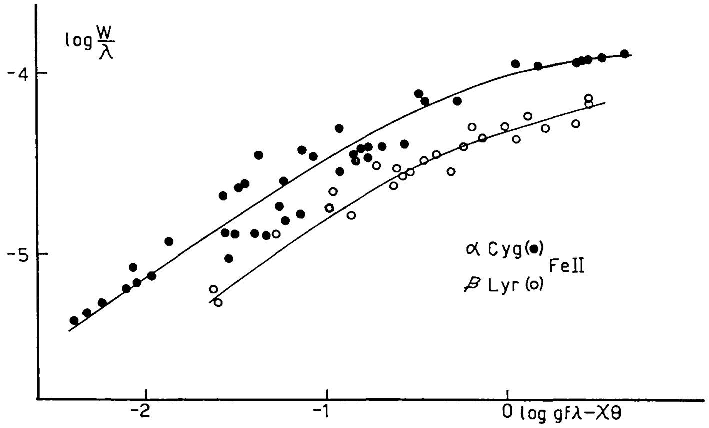

Fig. 8. Curve of growth for Fe II for α Cyg and β Lyr

Table 5. *Metallic abundances relative to Fe II*

	β Lyrae	α Cygni
log(Si II/Fe II)	0.00	+0.75
log(Mg II/Fe II)	+0.30	+0.70
log(Ti II/Fe II)	−3.50	−2.80
log(Cr II/Fe II)	−1.10	−1.30
log(Fe I/Fe II)	−5.30	−4.40

From the ionization equilibrium of Fe I and Fe II, using for the electron pressure of β Lyrae and α Cygni respectively $\log P_e = 1.25$ and $\log P_e = 0.76$ we find $(\Theta_\beta - \Theta_\alpha) = -0.13$ and assuming $\Theta_\alpha = 0.55$ it follows $\Theta_\beta = 0.42$.

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The abundances of the elements with higher excitation lines such as CII, NII, SiII, SiIII and SII, have been derived by comparison with γ Pegasi (ALLER and JUGAKU, 1959). Another value of the ionization temperature has been derived by the ionization equilibrium of SiII and SiIII. We find the following results:

Table 6. *Abundances relative to γ Pegasi*

Element	$\log(N/\varkappa)_\beta - \log(N/\varkappa)_\gamma$
CII	+1.28
NII	+1.70
SiII	+0.90
SiIII	−1.10
SII	+3.00

Assuming for γ Pegasi $\log P_e = 2.5$, from the ionization equilibrium of silicon it follows that $(\Theta_\beta - \Theta_\gamma) = +0.11$ and assuming $\Theta_\gamma = 0.27$ we have $\Theta_\beta = 0.38$. From these results we conclude that the more probable value for the temperature that should be used to compute the total abundances of the elements in the atmosphere of β Lyrae is $T = 12400$°K, $\Theta = 0.41$. This temperature is given by the evaluation of the color, of the FeII excitation, and of the ionization equilibria for FeII and FeI and for SiII and SiIII.

Table 7 gives the abundances with respect to the comparison stars. From the two abundance determinations for SiII with respect to α Cygni and to γ Pegasi we have $\log(\varkappa_\alpha/\varkappa_\gamma) = -0.14$. Assuming $\log(\varkappa_\alpha/\varkappa_\gamma) \sim 0$ we give the total number of atoms per gram of stellar matter with respect to the composition of the standard stars (last columns of Table 7).

Table 7. *Abundances of the elements relative to α Cygni and γ Pegasi*

Element	$\left[\frac{N_r}{\varkappa}\right]_{\beta\alpha}$	$\left[\frac{N_r}{\varkappa}\right]_{\beta\gamma}$	$\left[\frac{N}{\varkappa}\right]_{\beta\alpha}$	$\left[\frac{N}{\varkappa}\right]_{\beta\gamma}$	$[N]_{\beta\alpha}$	$[N]_{\beta\gamma}$
CII		+1.28		+0.58		+0.44
NII		+1.70		+1.48		+1.34
MgII	−0.99		+0.61		+0.61	
SiII	−1.30	+0.90	−0.26	−0.14	−0.26	−0.26
SII		+3.00		+2.04		+1.90
ScII	−0.76		+0.78		+0.78	
TiII	−1.25		+0.35		+0.35	
CrII	−0.35		+1.57		+1.57	
FeII	−0.55		+1.17		+1.17	
SrII	−0.38		+0.87		+0.87	

Notes to Table 7. The symbol $[X]_{ij}$ means $\log X_i - \log X_j$.

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6. Discussion of the results

Using $\Theta = 0.41$ we find for the abundances of hydrogen and helium: $\log N H = 23.75$ for hydrogen, $\log N H = 24.10$ for helium; He/H = 2.25. Using $\Theta = 0.38$ we find $\log N H = 23.90$ for hydrogen and $\log N H = 23.90$ for helium; He/H = 1.0.

From the comparison of the curve of growth for HeI and FeII we find also log(HeI/FeII) = +6.30 (assuming for the excitation temperature of helium $\Theta = 0.41$) or +5.60(for $\Theta = 0.38$) and for the total abundances log(He/Fe) = +4.40($\Theta = 0.41$) or log(He/Fe) = +3.70(for $\Theta = 0.38$) to be compared with the same value for the normal stars which is included between +4 and +3.3.

Table 8. *Abundances relative to silicon*

Element	Standard stars Average	γ Peg	α Cyg	β Lyr $\theta = 0.41$	$\theta = 0.38$	BD + 10° 2179	HD 30353	v Sgr
H	+4.38	+4.97	+4.13	+5.19	+4.84	+2.2	+0.3	+1.48
He	+3.66	+4.14		+5.54	+4.84	+4.7	+4.8	+3.12
C	+0.56	+1.55		+1.41		+1.1		+0.58
N	+0.76	+0.98	+1.21	+1.74		+1.3		+1.94
O	+1.29	+1.60	+0.99			—0.1		—0.06
Mg	+0.08	+0.92	+0.25	+1.12		—0.6	—0.3	+0.88
Si	0.00	0.00	0.00	0.00		0.00	0.00	0.00
S	—0.47	+0.77		+2.09				+0.38
Sc	—4.07		—4.47	—3.43			—4.6	—3.99
Ti	—2.22		—2.50	—1.89			—3.0	—2.49
Cr	—1.32		—3.29	—1.46			—2.5	—1.00
Fe	+0.33		—0.29	+1.14			—0.2	—0.27
Sr	—4.72			—3.80			—5.1	

* For H, He, C, N, O, Mg, Si, S, Fe we have used the average abundance values given by UNSÖLD (1955) and for Sc, Ti, Cr, Sr the average values given by HACK (1959).

Table 8 gives the abundances of β Lyrae, α Cygni, γ Pegasi, an average value of the abundances for the standard stars (UNSÖLD 1955, HACK 1959), and the abundances of the three hydrogen-poor stars v Sagittarii, BD + 10°2179 and HD 30353. Although we have derived the abundances of several elements with respect to iron, in our Table 8 we give the abundances with respect to silicon, in order to include in the comparison also the hydrogen-poor star BD + 10°2179, for which no determination of the iron abundance is available.

Concerning the ratio H/He, β Lyrae is much richer in hydrogen than the other three hydrogen-poor stars, and this is confirmed by the appearance of the Balmer spectrum which is almost normal for the surface temperature of the star. The excess of helium with respect to silicon is

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another peculiarity of this star, confirmed by the strength of the helium lines, corresponding to a B3-type spectrum rather than to a B8-type. However this excess can be explained at least partly as a temperature effect. In fact it is probable that the layers in which the He lines are formed are deeper and hotter than those in which the metallic lines originate. For example assuming $\Theta = 0.38$ for the excitation temperature of helium it follows that $\log(\mathrm{He/Si}) = 4.84$, a value which is not very different from that found for the standard star γ Pegasi.

Carbon, nitrogen, magnesium and sulphur are also in excess relative to the average of the normal stars, a peculiarity which is shared also from the comparison stars γ Pegasi (for carbon, magnesium and sulphur) and α Cygni (for nitrogen). The excess of scandium, iron and strontium can be at least partly apparent and due to the contribution of a cooler outer envelope of the star. It is probable that the slight deficiency of hydrogen makes the atmosphere of β Lyrae appreciably more transparent than that of the normal stars and this can explain the simultaneous presence in its spectrum of lines of FeI, FeII and FeIII.

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