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PROFILES OF HYDROGEN LINES IN TWO CLASS B STARS

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1. In an investigation by S. Verweij * the profiles of the first four members of the Balmer series were calculated for various values of temperature from 5600° to 18,600° and for seven values of gravity from log $g=1$ to log $g=7$. The influence of Stark effect in broadening the lines is taken into account by making various assumptions and computing the diffusion coefficients at the different pressures corresponding to values of optical depth from $\tau=0$ to $\tau=1$.

The observational data, which must form the ultimate test of the validity of the theoretical profiles, are not very numerous and exhibit rather marked contradictions which go to show how large are the uncertainties introduced by the method of calibration of a spectrum and the construction of the intensity profile from the microphotometer trace. Chances of error occur (1) in drawing the line which best represents the continuous background adjacent to the absorption line under consideration, (2) in the reduction data for the wedge or other intensity exposures and the application of these to any given trace, (3) in the determination of dispersion on the microphotometer trace which cannot always be relied upon to be a constant multiple of the dispersion on the original spectrogram. The difficulty in (1) is notorious and obviously affects the determination of the total spread of the wings, the central absorption of the line and the equivalent width or total absorption of the line. Both central and total absorption are affected by (2); and the error in (3) being cumulative may become quite considerable at a distance of 10 A. to 20 A. from the centre of line, thus introducing a large error into the computation of total absorption as well as into the estimate of line width. All these factors, and differences arising from lack of uniformity in photographic density on different spectrograms of the same star, may lead to quite large discrepancies in the resulting profiles. In view of this it seemed advisable to make a complete examination of as many Balmer lines as possible on the spectrograms of two Class B stars taken by Professor J. S. Foster, F.R.S., and one of the writers in 1932 at the Dominion Astrophysical Observatory in Victoria, B.C.

The material forming the basis of this paper comprises seven 3-prism spectrograms of γ Pegasi and one 1-prism and four 3-prism spectrograms of ι Herculis.

88	γ Peg	B2	$2^{m}.9$	H.D. 886
85	ι Her	B3	$3^{m}.8$	H.D. 160762

Microphotometer traces were made from these and intensity profiles constructed from the wedge calibration on each plate by means of the reduction data of Dr. C. S. Beals.†

2. *Half-widths.*—The profiles given in fig. 1 are plotted with the ordinate representing *intensity transmitted*, the continuous background being 1. The profiles from the 3-prism spectrograms of ι Her and γ Peg were reduced to a mean curve for each line.

In fig. 2 the theoretical profiles of Verweij are shown as dotted lines for $H\beta$, $H\gamma$, $H\delta$ for a star of temperature 16,800° with two values assumed for gravity, $\log g=4.0$ and $\log g=4.4$. His calculations do not provide the data for the residual intensities of the central cores of these lines in the case of the hotter stars. The full lines represent the

* Verweij, *Pub. Ast. Inst. Amsterdam*, 1936.

† Beals, *Pub. D.A.O., Victoria, B.C.*, VI, 9, 98–101, 1934.

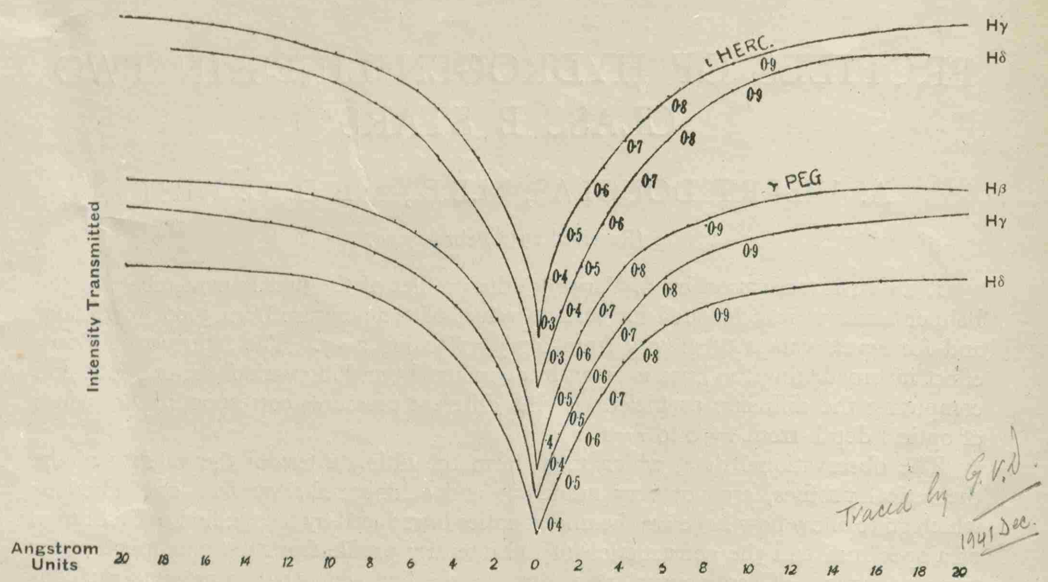

FIG. 1.

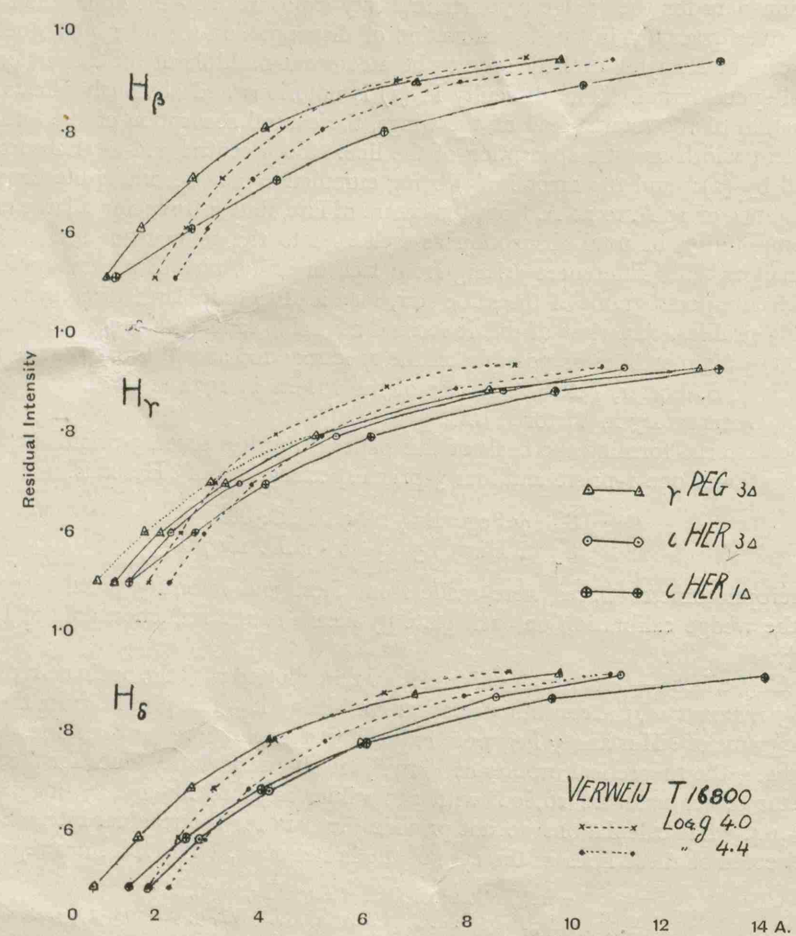

FIG. 2.

actual profiles for γ Peg and ι Her over the same range of residual intensity $r=0{\cdot}5$ to $r=0{\cdot}95$.

Considering first $H\beta$, it is seen that for $T=16{,}800°$, $\log g=4{\cdot}2$, the profile of γ Peg fits the Verweij values well at $r=0{\cdot}9$ and 0·95, but that the inner portion of the line is much less wide than theoretically expected unless the temperature be assumed higher or gravity very much less. For ι Her the discrepancy with theoretical profiles is very marked both at the core and at the extreme wing. γ Peg being a B2 star and ι Her B3, the hydrogen lines may be expected to be stronger in the latter than is actually the case.

In comparing the actual with the theoretical values for $H\gamma$ separate curves are shown for 1-prism and 3-prism spectra of ι Her, and in the case of γ Peg a dotted profile is added of the violet wing only, since the average wing is influenced by the heavy absorption of the red wing. C. T. Elvey has referred to this excess of absorption in the red wing of $H\gamma$ *, and as exact correction cannot be made for this, both the mean and violet wings are drawn. It is seen, however, that at ± 5 A. the wings become symmetrical. Here again the Verweij values give excessive widths near the line centre ($\pm 1{\cdot}5$ A.) and undervalue the amount of absorption in the outer wings.

The comparison between observation and theory in the case of $H\delta$ is almost exactly the same as in $H\beta$.

The effect of increasing temperature upon the Verweij profiles is to shift the curve bodily towards the line centre and *vice versa*. But since the central portion of a line is produced by absorption taking place at lesser optical depths than that producing the extreme wings, it is obviously impossible to fit a Verweij profile to the observed ones by adjusting temperature alone. His profiles are sensitive to change in gravity, and in order to bring observation and theory into line it would seem to be necessary to postulate increasing values of $\log g$ with increasing values of τ. However, there can be but little modification allowed from this source, and hence the discrepancy between theory and observation remains. It is, however, a discrepancy slightly different from that tentatively suggested by D. S. Evans † in the conclusion of his study of hydrogen lines in A0 stars—"This seems to indicate that the Verweij theory gives values of Stark broadening which are too great." In the B stars under consideration the calculated broadening appears to be too great only for the central portion of the lines where the residual intensity is less than 0·5 for ι Her and less than 0·7 for γ Peg.

3. *Total Absorption.*—In Table I the equivalent widths of lines are given measured in terms of total absorption over 1 A. and in italics are the percentages relative to $H\gamma=100$. The values obtained by C. T. Elvey ‡ and by E. G. Williams § are recorded to the nearest tenth. Accuracy to three significant figures scarcely seems to the present writers to be attainable. The dispersion is roughly indicated at the head of each column by the number of prisms used. In the final column are shown Verweij's computed values for a star having $T=16{,}800°$ and $\log g=4{\cdot}4$. The agreement for $H\beta$ in ι Her is good in every case. For $H\gamma$ the agreement is good save only for Williams's result, which appears to be extraordinarily low both for $H\gamma$ and $H\beta$, and indeed as we believe too low also for $H\epsilon$ and $H\zeta$. Our results indicate an increasing sequence from $H\beta$ to $H\epsilon$. A glance at the microphotometer trace given in fig. 3 will show that the $H\epsilon$ value may be an underestimate. The $H\zeta$ value includes the strong helium line λ 3888·6, but on the other hand the continuous background is very probably drawn in too low, thus considerably reducing the total absorption. The overlapping of the wings of adjacent Balmer lines would appear to have set in here, whether or not such overlapping is already effective between $H\epsilon$ and $H\delta$ as suggested by Elvey and Struve.||

The very low absorptions found by Williams, Elvey and ourselves for γ Peg relative to the Verweij data indicate that this star is considerably hotter than $T=16{,}800°$.

* Elvey, *Ap. J.*, **68**, 147, 1928.
† Evans, *M.N.*, **99**, 17, 1938.
‡ Elvey, *Ap. J.*, **71**, 191, 1930.
§ Williams, *Ap. J.*, **83**, 271, 1936.
|| Elvey and Struve, *Ap. J.*, **72**, 285, 1930.

TABLE I

Total Absorption

Unit 1 A.

	ι Her				*γ* Peg			Theoretical
	A. V. D. & 1Δ	D. C. W. 3Δ	C. T. E. 3Δ	E. G. W. 1Δ	D. & W. 3Δ	C. T. E. 3Δ	E. G. W. 1Δ	Verweij $T = 16{,}800°$ $\log g = 4{\cdot}4$
$H\beta$	6·4 *98*	...	6·5 *98*	6·5 *120*	4·6 *77*	3·4 *77*	4·9 *111*	6·6 *98*
$H\gamma$	6·5 *100*	6·1 *100*	6·6 *100*	5·4 *100*	6·0 *100*	4·4 *100*	4·4 *100*	6·7 *100*
$H\delta$	6·8 *105*	6·5 *107*	...	5·6 *104*	4·9 *82*	...	4·6 *104*	6·9 *103*
$H\epsilon$	9·0 *138*	...	...	6·2 *114*	...	...	5·1 *116*	...
$H\zeta$	7·7 *118*	...	...	6·1 *113*	...	...	5·3 *120*	...

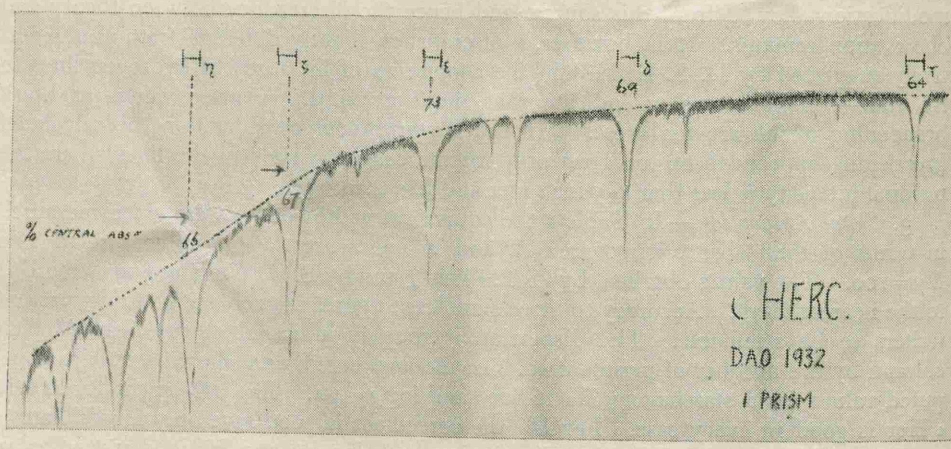

FIG. 3.—*Microphotometer tracing of Balmer lines in ι Herc.*

Plotting Verweij's total absorption against temperature for $\log g = 4{\cdot}4$ as in his Table XV, and making a risky extrapolation, the temperature corresponding to our values of total absorption for $H\beta$, $H\gamma$, $H\delta$ is from 19,000° to 21,000°, the lower value corresponding to our relatively high $H\gamma$ absorption.

It is to be noted that while our values for $H\beta$ and $H\gamma$ in the γ Peg spectrum are 36 per cent. higher than Elvey's, the ratio of the two lines is the same, namely 77 per cent. The low value of $H\delta$, which we find to be only 82 per cent. of $H\gamma$, is interesting. Verweij finds that for solar-type stars the absorption decreases from $H\alpha$ to $H\delta$, but for stars hotter than 8400° there is an increase over this range. Apparently the rate of increase is greatest at about 10,000°, while for hotter stars the rate of increase falls until at about 17,000° the four lines are of approximately equal intensity. At temperatures above this there seems to be a falling off of $H\delta$. According to Günther *, stars from B3 to A5 have $H\beta < H\gamma < H\delta$, whereas B0 to B2 stars have $H\beta$ the strongest of the three. We find $H\beta < H\gamma > H\delta$ for this particular B2 star, whereas E. G. Williams's results show $H\beta > H\gamma < H\delta < H\epsilon$ for both ι Her and γ Peg.

4. *Central Absorption.*—The percentage absorption at line centre is given in Table II. Values obtained by C. T. Elvey and by E. G. Williams are given for comparison. In addition Elvey's values for α CMa and J. D. Babbitt's † values for α Lyr are added.

TABLE II

Percentage Absorption at Line Centre

	ι Her				*γ* Peg			*α* CMa	*α* Lyr
	A. V. D. & 1Δ	D. C. W. 3Δ	C. T. E. 3Δ	E. G. W. 1Δ	D. & W. 3Δ	C. T. E. 3Δ	E. G. W. 1Δ	C. T. E. 1Δ	J. D. B.
$H\beta$	57	...	65	53	67	45	51	68	74
$H\gamma$	64	74	60	61	68	58	56	78	82
$H\delta$	69	78	58	63	62	...	61	82	84
$H\epsilon$	73	...	...	64	...	...	58	88	83
$H\zeta$	67	...	...	64	...	...	56	...	87
$H\eta$	66	...	...	...	...	...	59	...	81

The values which we give for $H\zeta$, $H\eta$, namely 67 and 66 per cent. respectively, are measured relative to an assumed position of the continuous background shown in fig. 3. Obviously these are too low, but perhaps not by more than a very few per cent. If we assume a 73 per cent. central absorption for both $H\zeta$ and $H\eta$ it is possible to calculate back to the position where the continuous background should be drawn in. It is indicated in fig. 3 by arrows, and many investigators would no doubt be content to draw the background lower than this.

5. *Acknowledgment.*—The writers are indebted to Miss D. E. Guignard for considerable assistance in making many of the microphotometer tracings and in the reduction of these to line profiles.

Summary

Theoretical line widths computed by Verweij are compared with profiles of certain Balmer lines in spectra of γ Peg and ι Her. Comparison is likewise made regarding total absorption in five Balmer lines and an estimate of the temperature of γ Peg is indicated. The percentage absorption at line centre is compared with the observations of other investigators.

[It may be pointed out that the hydrogen profiles predicted by Verweij's theory, with which the observations of this paper are compared, are based on Pannekoek's calculated values of the continuous absorption coefficient k (*Pub. Ast. Inst. Amsterdam*, No. 4, 1935). These values have since been subject to revision by Pannekoek himself in an addendum to the paper quoted, and by others.—ED.]

* Günther, *Zs. f. Ap.*, 7, 106, 1933.

† Babbitt, *Can. Journal Research*, A, 15, 161–180, 1937.

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