DEPARTMENT OF MINES AND RESOURCES, CANADA
MINES, FORESTS, AND SCIENTIFIC SERVICES BRANCH

PUBLICATIONS
OF THE
Dominion Astrophysical Observatory
VICTORIA, B.C.

Volume VII, No. 26

THE INTENSITIES OF ISOTOPIC CARBON BANDS IN THE SPECTRA OF TWENTY-ONE R-TYPE STARS

BY ANDREW McKELLAR

ABSTRACT.—An historical resume is given of investigations of the abundance ratio of the carbon isotopes (C^{12}/C^{13}). It is noted that the C^{12}/C^{13} abundance ratio in terrestrial and meteoritic carbon is about 90. In nearly all stellar spectra of types R and N, the bands of the C_2 Swan System involving C^{13} appear with considerable strength. Most previous investigators, while agreeing that this probably indicated a relatively high abundance of C^{13}, were undecided on possible variations of the abundance ratio from star to star.

Observational data obtained at Victoria, consisting of sixty-three single-prism spectrograms of twenty-one R-type stars, are described. The spectrophotometric technique used to obtain intensity profiles and to measure the relative intensities of the 1,0 main and isotopic bands of the C_2 Swan System (λ4747, $C^{12}C^{12}$; λ4744, $C^{12}C^{13}$; and λ4752, $C^{13}C^{13}$) are outlined.

The problem of obtaining the relative abundance of C^{12} to C^{13} from the intensities of the bands is discussed. Reasons are given to justify the simplifying assumption that for bands up to moderate strength, the number of absorbing molecules may be taken as proportional to the intensity of the band. The relative abundances obtained are listed. For six stars, the bands are too strong to give reliable results. For three stars, there is very little, if any, trace of C^{13}, the *minimum* values of the C^{12}/C^{13} ratio being 30, 60, and 70. The remaining twelve stars are found to exhibit an unexpected and remarkably constant C^{12}/C^{13} abundance ratio, the mean value being 3·4 with a standard deviation of only 0·16. One of the twelve stars, V *Arietis*, with an abundance ratio of 4·8, may be an intermediate case. In the absence of any other apparent physical explanation, the results are taken to indicate that two groups may be distinguished among the R-type stars, one characterized by a C^{12}/C^{13} abundance ratio of the order of 50 or more, and the other with a ratio about 3.

The final section outlines two possible explanations of the above result. The first explanation arises from recent work on the origin of the chemical elements by Klein, Beskow and Treffenberg whose different "models" yield different abundance ratios of C^{12}/C^{13}. The second, an attractive hypothesis resulting from a discussion with Professor E. Fermi, explains the two groups of stars with different C^{12}/C^{13} abundance ratios in terms of a possible train of events connected with the initiation of the energy-producing carbon-nitrogen cycle. The stars with the low ratio would be those in which the carbon-nitrogen cycle has not yet started while in stars with the high ratio, the cycle has become established.

INTRODUCTION

The carbon isotope of atomic weight thirteen, C^{13}, was detected in the laboratory in 1929 by King and Birge[1]. They identified with the molecule $C^{12}C^{13}$ a weak band-head at λ4744 accompanying the strong λ4737 1,0 band of the Swan system. Shortly thereafter Sanford[2] showed that the λ4744 absorption band, previously observed in the spectra of stars of classes R and N, was doubtless the $C^{12}C^{13}$ band. Subsequently, Menzel[3] pointed out that an additional weaker band, occurring at λ4752 in some of the stellar spectra, was probably the 1,0 band of the Swan system arising from the $C^{13}C^{13}$ molecule.

[1] *Nature*, **124**, 127, 1929 and *Ap. J.*, **72**, 19, 1930.
[2] *P. A. S. P.*, **41**, 271, 1929.
[3] *P. A. S. P.*, **42**, 34, 1930.

It was at once apparent that in the spectra of many of the cool carbon stars, the bands involving the heavier isotope, C^{13}, (hereafter called the *isotopic* bands to distinguish them from the *main*, $C^{12}C^{12}$ bands), appeared with intensities, relative to the $C^{12}C^{12}$ bands, considerably greater than in laboratory sources of the Swan system. This raised an interesting and possibly important problem. Do the apparently different strengths of the isotopic bands indicate real differences between the abundance ratio of C^{12} to C^{13} from one stellar atmosphere to another and between stellar and terrestrial samples of carbon, or are they explainable on some other physical basis?

Considering first terrestrial carbon, samples have been investigated for the abundance ratio of C^{12} to C^{13} in two ways, by the mass spectrograph and by spectrophotometric measurements on the Swan bands of C_2. Examples of the results with the mass spectrograph include those of Murphey and Nier[4] and of West[5]. Murphey and Nier found a mean abundance ratio $C^{12}/C^{13} = 89 \pm 2$ for carbon from various natural sources. Different samples, however, showed small but probably significant differences, ranging up to five per cent. West examined many samples of petroleum from different localities and found the C^{12}/C^{13} abundance ratio sensibly constant at 94·1 with a probable error of less than one per cent. Jenkins and Ornstein[6] had previously, from intensity measurements on the C_2 Swan bands, obtained a ratio of 106, with a considerably larger probable error than the mass-spectrographic determinations. Hence, the abundance ratio of C^{12} to C^{13} for terrestrial carbon may be taken as about 90 to 1.

Carbon is present in meteorites. Jenkins and King[7] have made a direct spectrophotometric comparison of the carbon bands produced from samples of meteoritic carbon and ordinary Acheson graphite. The relative intensities of the main and isotopic bands were found to be the same within less than one per cent. Also, some of Murphey and Nier's samples were of meteoritic origin, and they found for these no marked differences from other samples. Therefore, to the extent of present knowledge, the isotopic constitution is the same for meteoritic and terrestrial carbon.

The spectrum of the sun shows the C_2 Swan bands only very weakly but the violet CN bands appear with somewhat more strength. When the positions of the main $C^{12}N^{14}$ and isotopic $C^{13}N^{14}$ lines of the λ3883, 0,0 CN band are plotted on the *Utrecht Photometric Atlas of the Solar Spectrum*, no definite evidence of the $C^{13}N^{14}$ lines is found. One can estimate that the relative intensity of $C^{12}N^{14}$ to corresponding $C^{13}N^{14}$ lines is at least 15. This minimum value of 15 eliminates a low abundance ratio of C^{12} to C^{13} but leaves the possibility that the ratio (90) found for terrestrial and meteoritic samples may obtain also for solar material.

Recently O. C. Wilson[7a] has examined for the possible presence of components involving C^{13}, the plates of W. S. Adams which show best the CH and CH^+ molecular interstellar lines. He found no evidence of the isotopic lines and concluded that in the interstellar matter, the C^{12}/C^{13} abundance ratio must have a *minimum* value of 5.

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[4] *Phys. Rev.*, **59**, 771, 1941.
[5] *Geophysics*, **10**, 406, 1945.
[6] *Pr. Kon. Akad. Wetenschappen*, Amsterdam, **35**, 1212, 1932.
[7] *P. A. S. P.*, **48**, 323, 1936.
[7a] *P. A. S. P.*, **60**, 198, 1948.

Contributions to the study of the intensities of the main and isotopic carbon bands in stellar spectra have been made by various investigators. In 1930, Menzel[3], from an examination of the 1,0 Swan bands on some spectrograms, estimated that the abundance ratio of C^{12} to C^{13} was not more than 10 in the atmospheres of the N-type stars. Wurm[8] questioned the results of Menzel and indicated that caution should be exercised in going from band intensities to relative abundances. He suggested a procedure of comparing a main band with an isotopic band of about equal intensity in the same system. Then a value of the isotopic abundance ratio could be obtained from the calculated relative intensities of the two transitions. Parenthetically, it may be pointed out that while attractive in theory, over extensive band systems such as the C_2 Swan and CN violet bands, this method would be liable to large and uncertain errors because of probable variations in general absorption or opacity with wave-length and because of the considerable uncertainties of the calculated band intensities.[9] In 1936, McKellar[10] reported on the measurement of the intensities of the main and isotopic C_2 bands for the R-type star H.D. 182040, and gave the minimum abundance ratio C^{12} to C^{13} as 43. Sanford[11], in 1940, published wave-length measurements on spectra of class R, in which he identified isotopic bands involving C^{13} in all sequences of the Swan bands except the 0,0 sequence where the isotope shift is negligible. He detected, also, the $C^{13}N^{14}$ companions to the λλ4216 and 4606 violet CN bands. In the same paper he noted that the 0,2 Swan bands of $C^{12}C^{12}$ and $C^{12}C^{13}$ at λλ6192 and 6168, respectively, had approximately the same total absorptions in some cases. In 1942, Shajn[12] gave the results of both wave-length and intensity measurements on the C_2 Swan bands in the spectra of a number of stars of type N. He concluded that the intensity ratio of $C^{12}C^{12}$ to corresponding $C^{12}C^{13}$ bands varied from 0·9 to 2·5 and the abundance ratio C^{12}/C^{13} varied from 2 to 20, for the few N-type stars studied. While convinced of the high stellar concentration of C^{13} relative to C^{12}, Shajn left open the possibility that the apparent variation of the abundance ratio from star to star might not be real but arise from differences in physical conditions. More recently Mme. Daudin and Fehrenbach[13] have reported on measurements of the intensities of main and isotopic bands in the C_2 Swan and the red CN systems in the spectra of four stars of class N. In view of the very recent revision of the vibrational analysis of the red CN system[14], it is apparent that the absorption features measured as $C^{13}N^{14}$ bands by Daudin and Fehrenbach must have been incorrectly identified, so the results on the red CN bands are of no value. From the C_2 bands, they list abundance ratios, C^{12}/C^{13}, from about 2 to 3. Herzberg[15] has also noted that the bands of the λ6191 C_2 sequence involving C^{13} showed very clearly in the spectra of two N-type stars. This he considered as confirming the conclusion of others concerning the relatively high stellar abundance of C^{13}.

The previous work on the intensities of the main and isotopic carbon bands in stellar spectra may be summed up as follows:

(1) in all the investigations except Sanford's, the work was done on N-type spectra;

[8] *Zs. f. Ap.*, **5**, 260, 1932.
[9] A. McKellar and W. Buscombe, *These Publications*, **7**, No. 24, 1948.
[10] *P. A. S. P.*, **48**, 216, 1936.
[11] *P. A. S. P.*, **52**, 203, 1940.
[12] *Bull. Abastumani Ap. O.*, No. 6, 1, 1942; *Observatory*, **64**, 255, 1942.
[13] *C. R.* **222**, 1083, 1946; *Observatory*, **66**, 205, 1946.
[14] G. Herzberg, and J. G. Phillips, *Ap. J.*, **108**, 163, 1948.
[15] Report of the Yerkes and McDonald Observatories for 1946, *Astron. Journal*, **52**, 149, 1947.

(2) the conclusion that the isotopic bands occurred with relatively great strength was reached by all observers, who in general agreed that this indicated a relatively high concentration of C^{13} to C^{12};

(3) the question of the variation of the relative intensities of main and isotopic bands from star to star of type N was not so firmly established, although suggested by Shajn and by Daudin and Fehrenbach. From Sanford's photographs and statements, it is certain he was aware that while some R-type stars showed strong isotopic bands, a few showed little, if any, evidence of them;

(4) the problem of proceeding from relative intensities of bands to relative isotopic abundances was noted and discussed, but was not solved;

(5) short-comings in the work included *(a)* in any one investigation only a few stars were studied, and *(b)* clear descriptions of the photometric techniques or procedures used were not given in any case.

TABLE 1. LIST OF STARS OBSERVED

Star		α (1900)	δ (1900)	Spectral Type*		Magnitude	Number of Plates
H.D. 1994		0^h $19^m.1$	+53° 54′	R6	$C4_5$	9·7	1
5223		48·9	+23 32	R3	$C2p_2$	8·8	4
10636		1 38·7	+53 28	R6		9·9	1
13826	V *Ari*	2 09·6	+11 47	R5	$C5p_5$	8·3–9·0	3
16115		30·2	− 9 53	R4	$C2_3$	8·3	3
19557		3 03·7	+57 31	R6	$C4_5$	8·1	3
25408		57·2	+61 32	R8	$C5_3$	7·9	5
36972	S *Cam*	5 30·2	+68 45	R8e		7·8–10·8	2
52432		6 56·1	−03 06	R6	$C4_4$	7·5	3
56167	RU *Cam*	7 10·9	+69 52	R0	$C0_1$	7·9–9·0	2
76396		8 50·8	+51 49	R4	$C1p_2$	8·8	3
76846		53·6	+34 09	R1		9·2	3
77234		56·2	+50 29	R6		9·5	1
79319		9 08·3	+14 37	R6	$C4_4$	8·9	3
112869		12 54·7	+38 20	R6p	Cp_5	9·2–9·6	3
156074		17 10·4	+42 15	R0	$C1_2$	7·7	6
182040		19 17·7	−10 53	R2	$C1_2$	7·0	7
187216		43·8	+85 09	R3		9·6	2
197604		20 39·7	+34 43	R4		9·8	2
209621		21 59·7	+20 34	R3	$C3p_2$	8·8	3
223392		23 44·0	+05 50	R3	$C3_2$	8·8	3

*The R spectral types and magnitudes are taken from Sanford's list (*Ap. J.*, **99**, 145, 1944). In one case, H.D. 13826, his classification, RO, has been changed to R5.
The C classifications are those proposed by Keenan and Morgan, (*Ap. J.*, **94**, 501, 1941).

Some years ago a program of observations of the spectra of R- and N-type stars was begun at Victoria, the primary purpose of which was a spectrophotometric study of the intensities of the main and isotopic carbon bands. Attention was directed particularly toward the 1,0 bands of the C_2 Swan system at λλ4737, 4744, and 4752. The faintness and extreme redness of most of the cool carbon stars has resulted in the plates being accumulated rather slowly. However, sufficient material is now available for twenty-one R-type and twenty-five N-type stars. The data on the R-type stars are treated in this publication. The R-type stars have been studied first for several reasons, the two chief

SPECTRA OF R-TYPE STARS, λ4380–λ5000

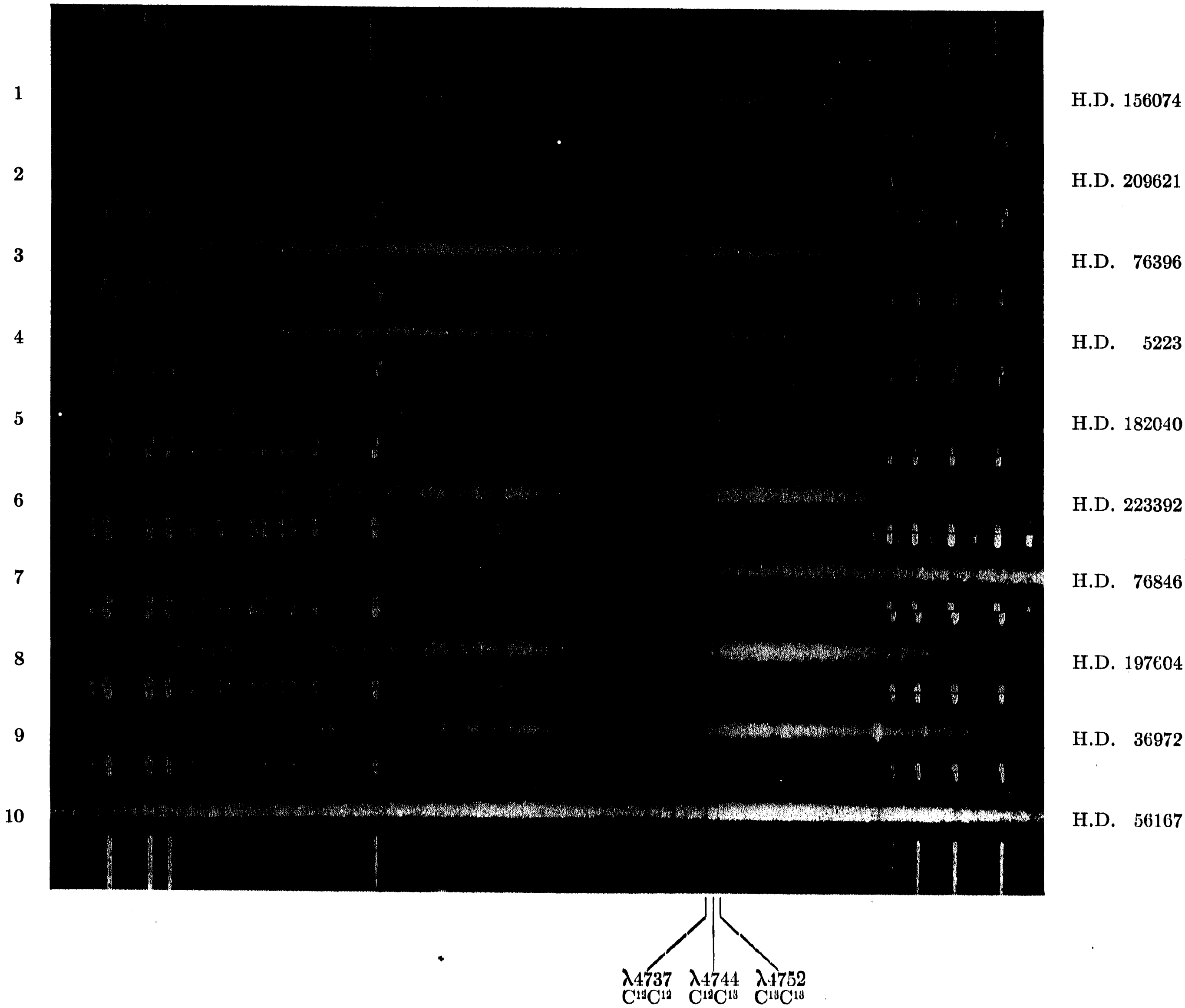
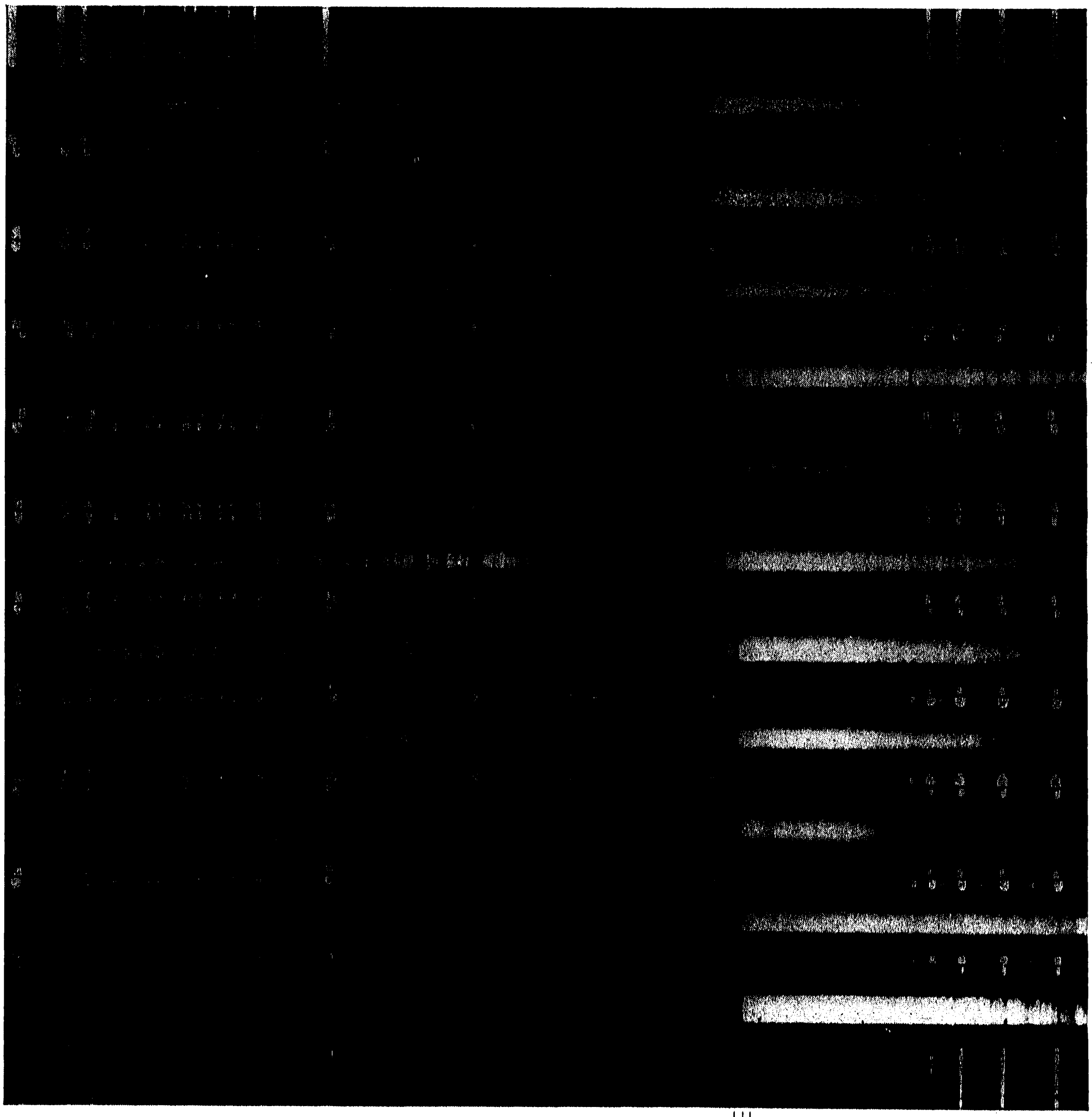


PLATE VIII

SPECTRA OF R-TYPE STARS, λ4380–λ5000



11 H.D. 112869
12 H.D. 13826
13 H.D. 187216
14 H.D. 16115
15 H.D. 1994
16 H.D. 25408
17 H.D. 79319
18 H.D. 10636
19 H.D. 77234
20 H.D. 19557
21 H.D. 52432

λ4737 $C^{12}C^{12}$ λ4744 $C^{12}C^{13}$ λ4752 $C^{13}C^{13}$

PLATE IX

ones being *(a)* the very difficult problem of locating properly the position of the continuum at λ4740 is easier for the R-type than for the N-type spectra, and *(b)* since generally the C_2 band absorption is weaker for the R-type stars, the assumption made later regarding the curve of growth is more likely to be valid.

THE OBSERVATIONAL DATA

The spectrograms were obtained with the single-prism form of the Victoria stellar spectrograph using the cameras of medium (70 cm.) and short (42 cm.) focal length. These give dispersions at λ4737 of 42 and 70 A. per mm., respectively. Over the course of the observations slit widths varying from 0·05 to 0·10 mm. were used, corresponding at λ4737 to a range in projected slit width at the plate from 1·3 to 2·5 A. Reproductions of spectrograms of the twenty-one stars are shown in Plates VIII and IX.

The stars observed are listed in Table 1, which contains data on their spectral types, positions, magnitudes, and the number of plates obtained. It had been planned to secure at least three plates of each star. For fourteen stars this objective was attained; for four stars there were two plates, and for the remaining three stars, but a single plate. In all, there were sixty-three plates of the twenty-one stars. Close agreement was found between the intensity profiles from the individual spectrograms which were combined to obtain the mean profile for a given star. Therefore, while it would have been desirable to have had the three plates of every star, it is felt that even for the three stars represented only by a single plate, the result should be reliable. Incidentally, it may be noted that for the four stars which are variables, the present observations showed no appreciable changes in the intensity of the C_2 Swan bands from plate to plate.

The plates had all been calibrated for spectrophotometric purposes using a source of continuous radiation and a rapidly rotating step-sector in front of the slit of an auxiliary spectrograph. The calibration curves yielded by this arrangement have been checked against those obtained using several other different devices, including two different step-slits, a step-wedge loaned by Dr. M. Minnaert, and two other step-wedges of platinum sputtered upon quartz calibrated at the Massachusetts Institute of Technology. The agreement in each case was good.

Microphotometer tracings were made for each plate and were run through the semi-automatic intensitometer[16] to derive the intensity *versus* wave-length profiles. The position of the continuous spectrum was estimated by joining the highest points between the λ4860 and λ4740 regions, and then extending this line to meet the highest peaks between the end of the 1,0 sequence of the Swan bands and λ4383 where the 2,0 sequence begins. The latter intensity maxima were generally the same from star to star; one of the most reliable occurs at λ4438. For each of the stars, the intensitometer curves from the several plates were superposed and a mean profile of the region of the 1,0 main and isotopic carbon bands was made.

The mean profiles for each of the twenty-one stars constitute the fundamental data upon which results to be described are based. Probably these profiles will not be materially improved upon until the stars are photographed with considerably higher spectrographic resolution. They are therefore reproduced in Figs. 1 to 7, in order to be available for interpretation or treatment different from that given in this publication.

[16] C. S. Beals, *J. R. A. S., Canada*, 38, 65, 1944.

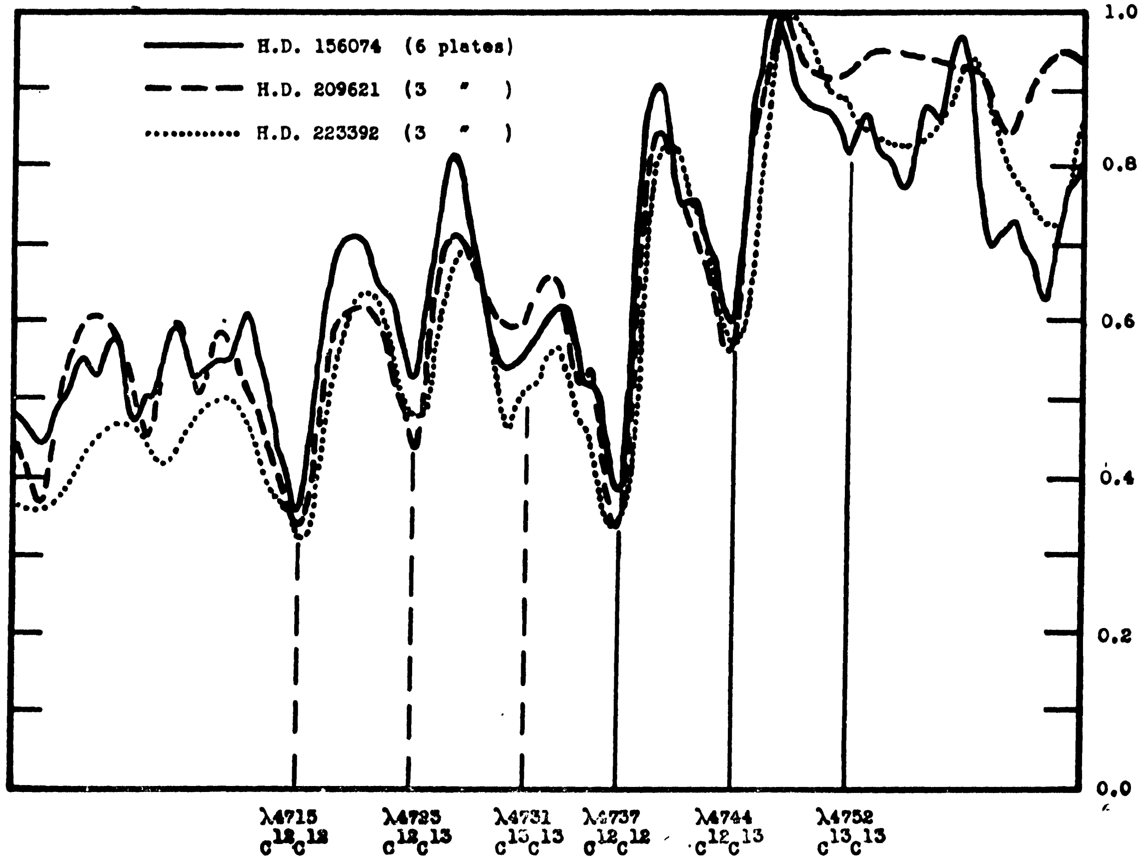


Fig. 1—Intensity Profiles, λ4740 region, in the Spectra of H.D. 156074, H.D. 209621, and H.D. 223392.

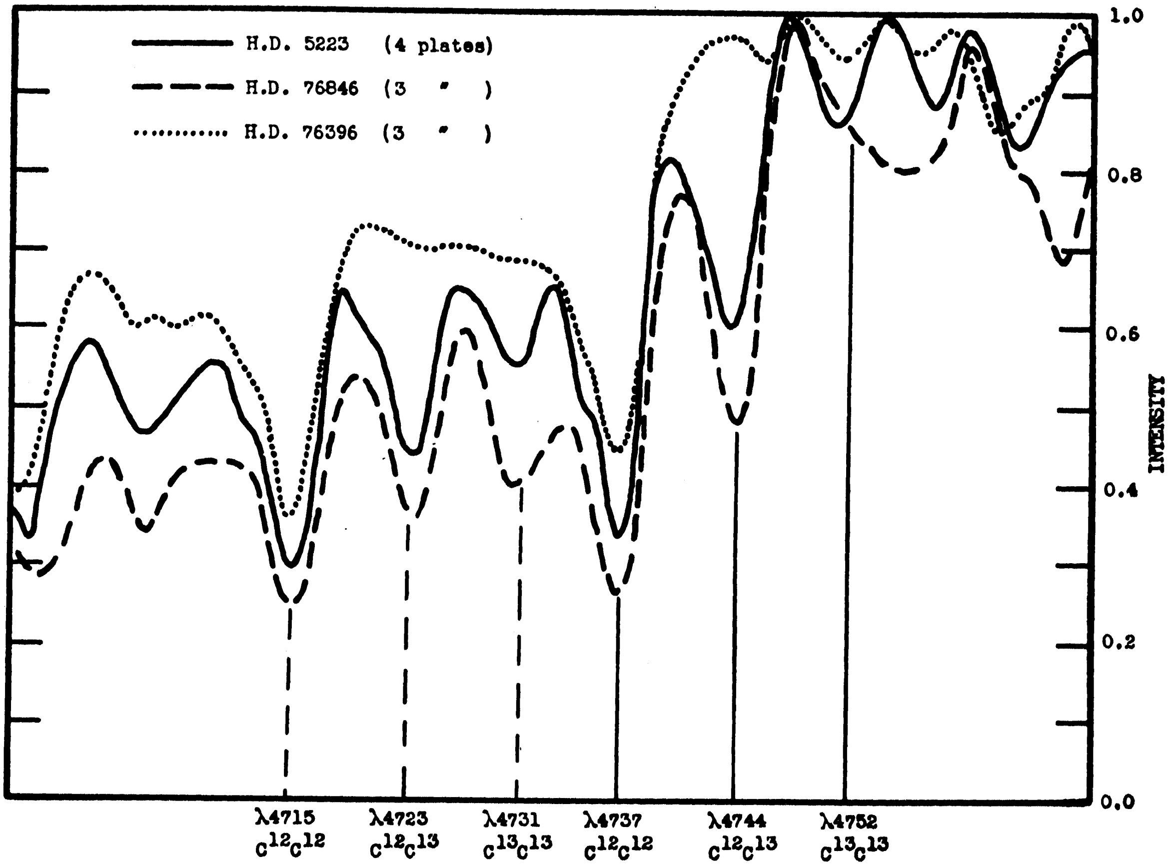


Fig. 2—Intensity Profiles, λ4740 region, in the Spectra of H.D. 5223, H.D. 76846, and H.D. 76396.

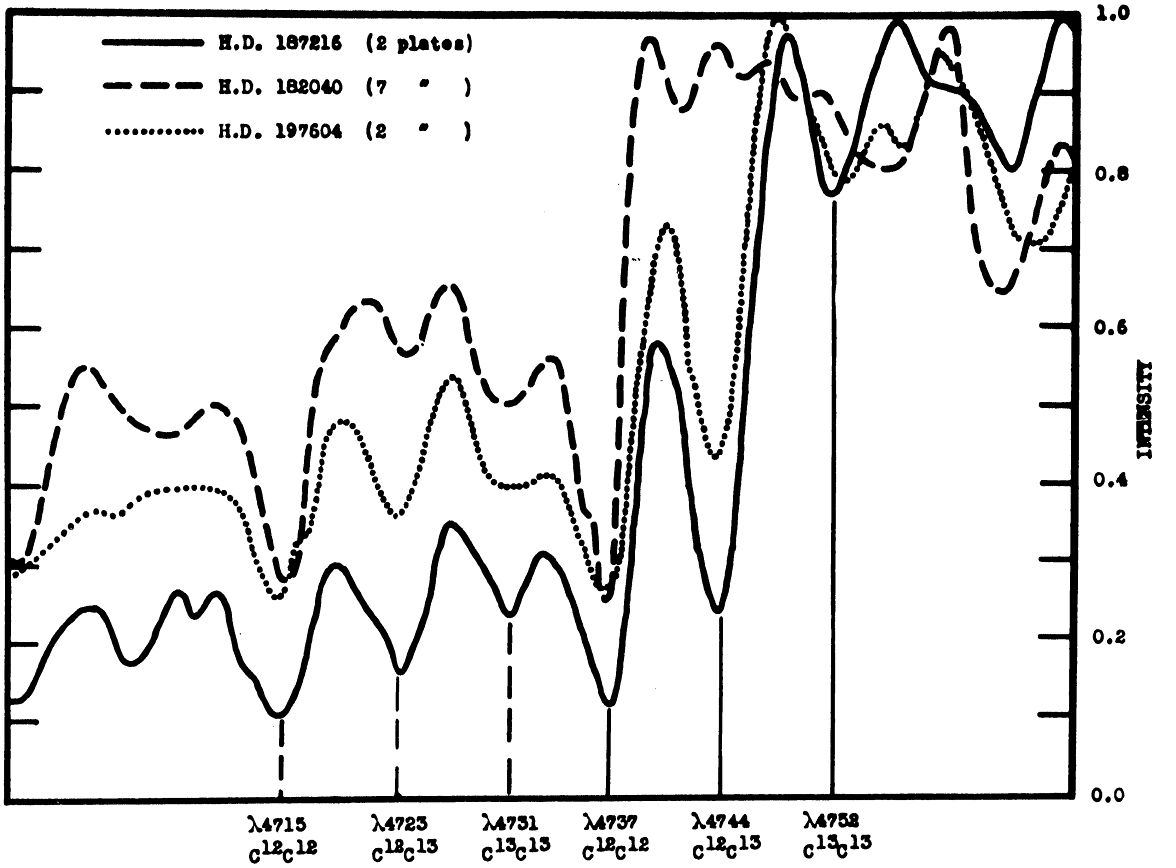


Fig. 3—Intensity Profiles, λ4740 region, in the Spectra of H.D. 187216, H.D. 182040, and H.D. 197604.

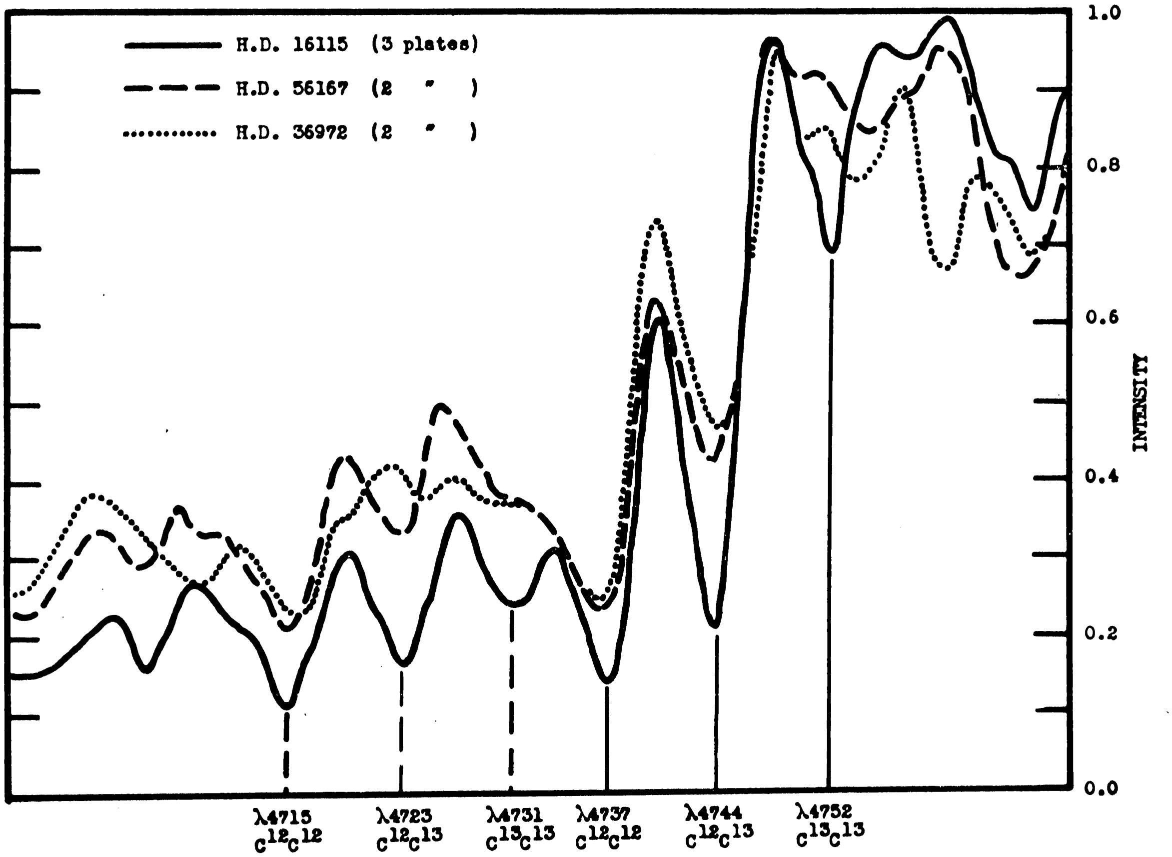


Fig. 4—Intensity Profiles, λ4740 region, in the Spectra of H.D. 16115, H.D. 56167, and H.D. 36972.

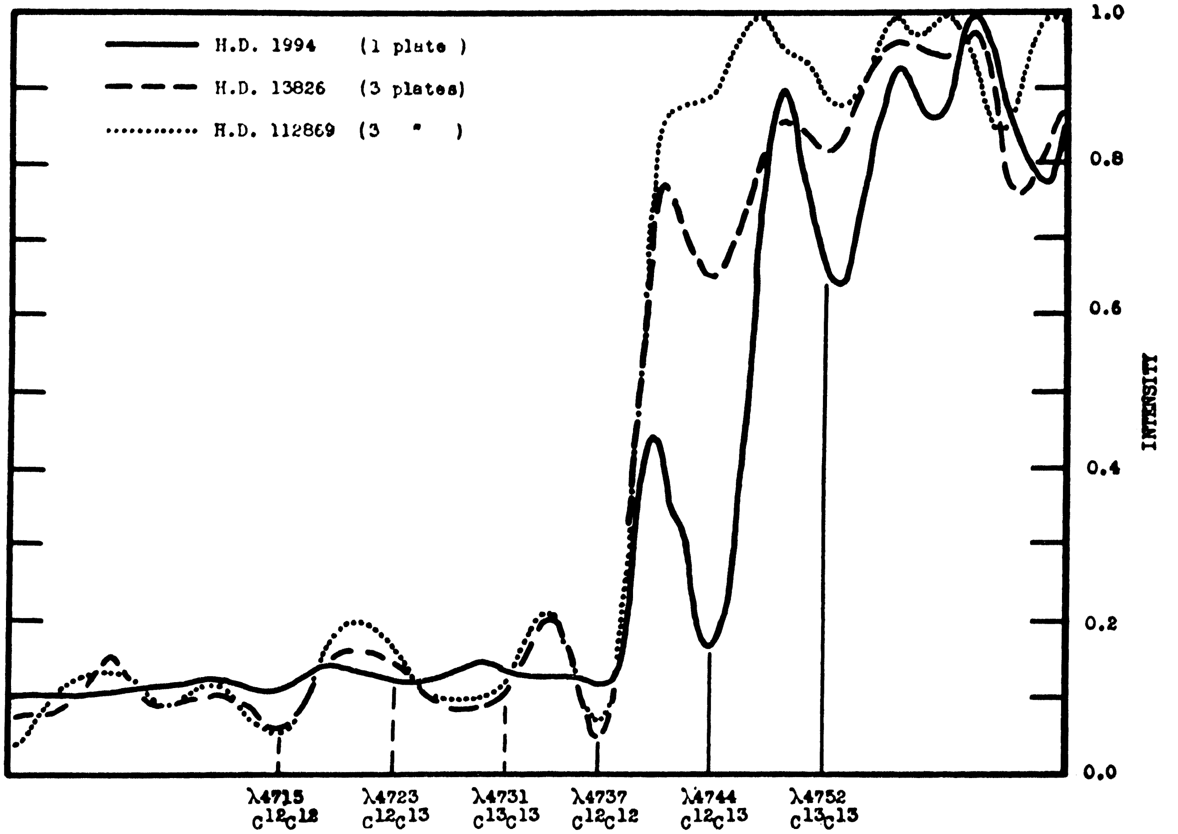


Fig. 5—Intensity Profiles, λ4740 region, in the Spectra of H.D. 1994, H.D. 13826, and H.D. 112869.

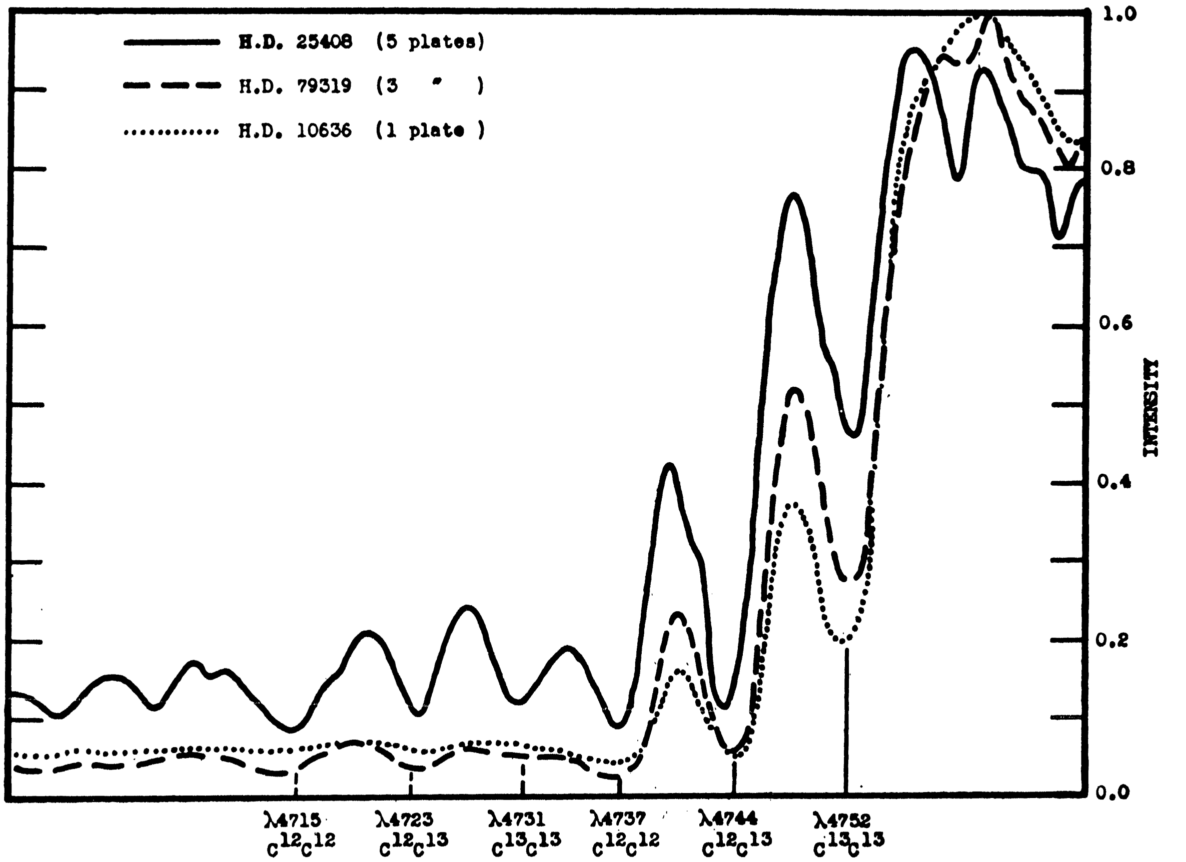


Fig. 6—Intensity Profiles, λ4740 region, in the Spectra of H.D. 25408, H.D. 79319, and H.D. 10636.

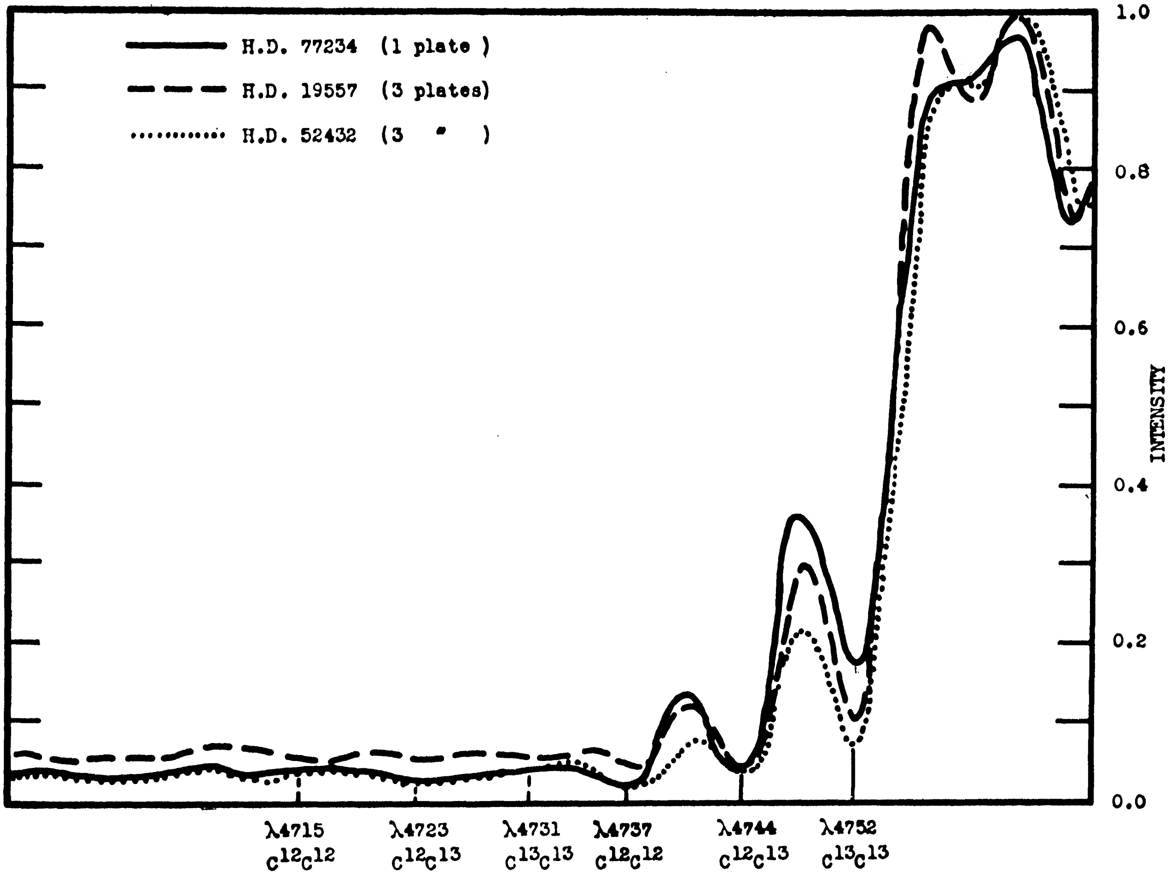


FIG. 7—Intensity Profiles, λ4740 region, in the Spectra of H.D. 77234, H.D. 19557, and H.D. 52432

MEASUREMENT OF THE INTENSITY PROFILES

The C_2 Swan bands are degraded toward the violet. They represent a $^3\Pi$, $^3\Pi$ transition with vector coupling approximating Hund's case *b*. Near case *b*, the multiplet splitting is very small. Although each band has three *P* branches and three *R* branches, the triplet nature of the lines is only apparent under dispersion higher than that usually attained by stellar spectrographs. With the dispersion used in the present work, even the line structure of the bands is not resolved. The multiple *P* branches form the band heads. For the 1,0 band of C^{12} C^{12}, the origin is at λ4731 and the head at λ4737·1. The distance from origin to head is just a little less than the successive separations of the main and two isotopic heads, 7·6 A. It is therefore convenient to measure the relative intensities of the main and isotopic bands by comparing the integrated intensities of their *P* branches between the band origins and band heads.

It should be recalled that except for a difference in scale by the amount of the mass factor ρ^2 (in these cases 1·04 between successive isotopic species) and the properties due to symmetry and nuclear spin, the rotational structures of the main and isotopic bands are the same. The difference in scale factor, of course, could be and was taken into account. Therefore, with the dispersion used in the present work and to the limits of photometric and other accidental errors, it should be permissible to take the band structures as identical for purposes of comparing the intensities of the main and isotopic bands.

Before a detailed description of the procedure used in measuring the intensities of the *P*-branch regions of the main and isotopic bands is given, it is instructive to examine samples of the three cases which occur. Plate X shows enlargements of the λ4737 region of the spectra of three of the R-type stars. For H.D. 182040, the $C^{12}C^{12}$ bands are present with moderate strength but no isotopic bands are seen with certainty. For H.D. 5223, the main bands are actually slightly weaker than for H.D. 182040, but the $C^{12}C^{13}$ bands are clearly seen. For H.D. 19557, bands arising from all three molecular species are present and are so strong that significant measurements on any but the λ4752 head of $C^{13}C^{13}$ are very difficult, if not impossible, to make. The intensity profiles corresponding to the three spectrograms of Plate X may be seen in Figs. 2, 3, and 7.

One of the main problems that arises in connection with measuring the total intensities of the head-forming *P* branches is blending. Where all three bands are present the *P* branches of the λ4744 isotopic band are superposed on the *R* branches of the λ4752 band and the *P* branches of the λ4737 main band on the *R* branches of both isotopic bands. Where only the λ4737 and λ4744 bands are present, the *P* branches of the former are superposed on the *R* branches of the latter. Where only the main λ4737 band is of appreciable intensity, the problem does not arise. The following method was used to allow for blending between the main and isotopic bands. For the three cases where the intensity of both isotopic bands were negligible, the central intensity of the *P*-branch minimum was plotted against the mean residual intensities of the regions 7·5 Angstrom units wide centred at 7·5 and 15 Angstrom units, respectively, to the violet of the *P*-branch minimum. The two curves thus obtained enabled one to read off the mean position of the effective continuous spectrum for the head forming part of the *P* branches for the one or two bands to the violet of the first one of the three (counting from the red) of appreciable intensity. For example, in the illustrative case of H.D. 16115 shown in Fig. 8, the effective continuum for the $C^{13}C^{13}$ *P* branch is, of course, unity while that for $C^{12}C^{13}$ was found to be 0·93 and for $C^{12}C^{12}$, 0·50. The areas of the *P* branches under their respective continua, shown cross-hatched in Fig. 8, were measured by a planimeter. The regions above the continua are absorbed partly by the *P* branches and partly by the *R* branches of the more redward bands, so the real absorption of the *P* branches must be greater than the value found as above by the planimeter. To arrive at a corrected intensity, the procedure proved valid by Thackeray for certain cases of blending was used[17]. While in the present case it may not be strictly applicable and may involve an approximation, no better procedure was apparent. Thackeray showed that when the equivalent width was measured with respect to the lowered continuum as unity, it must be further divided by the residual intensity of the lowered continuum. That is, the areas planimetered, when the effective continuum was found to be less than 1·0, were divided by the squares of the respective values of the continua, to arrive at the equivalent widths. In the example of Fig. 8, the areas of the three cross-hatched regions were divided by 0·25, 0·865, and 1·0, respectively.

A further correction was made for blending. From the intensity profiles of the three stars having no appreciable $C^{12}C^{13}$ bands, a mean value for the extraneous absorption (atomic and/or molecular) over the region, origin to head, of that band was found. Similarly, from the six stars with spectra showing no appreciable $C^{13}C^{13}$ bands, a mean

[17] *Ap. J.*, **84**, 433, 1936.

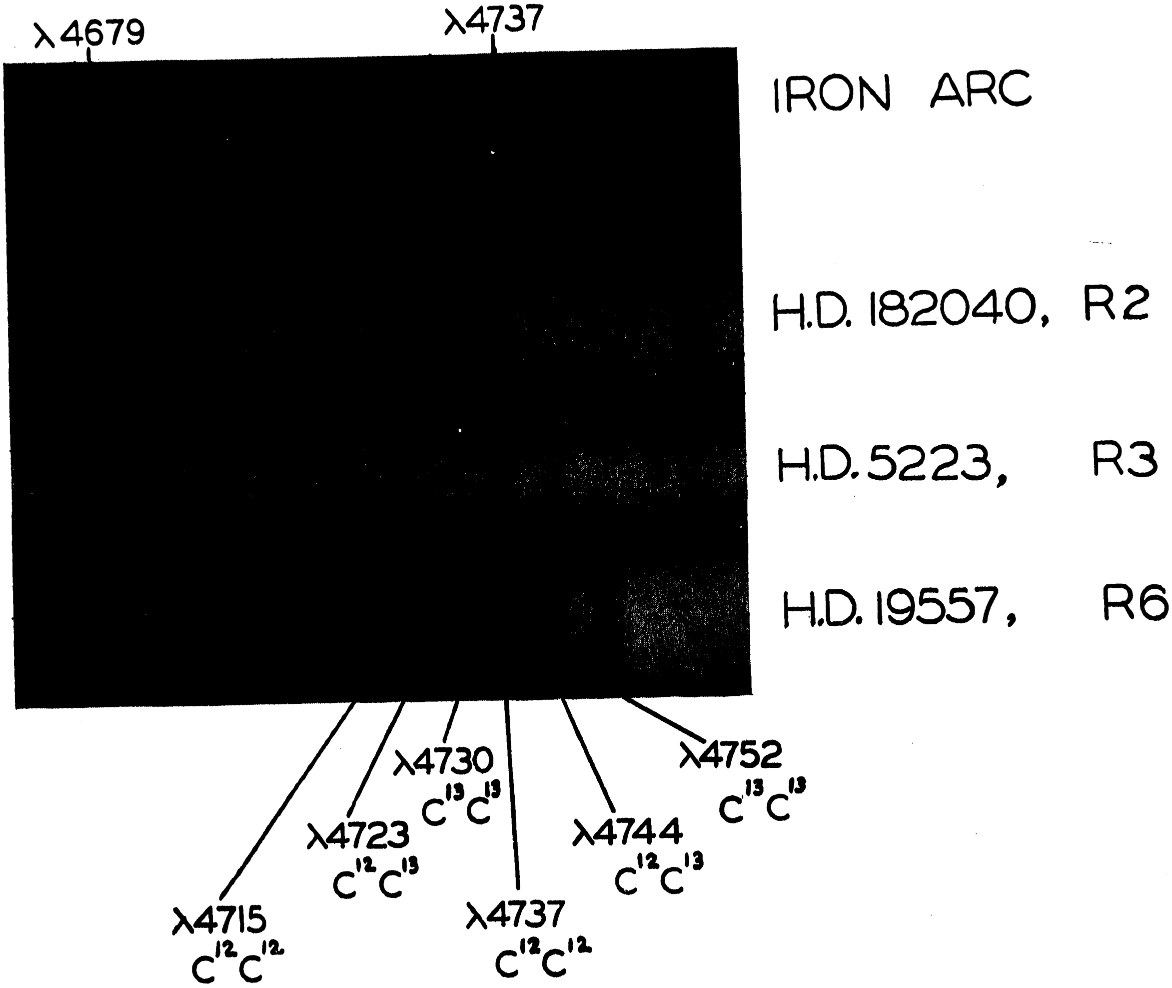

λ4679
λ4737
IRON ARC
H.D. 182040, R2
H.D. 5223, R3
H.D. 19557, R6
λ4715 C12C12
λ4723 C12C13
λ4730 C13C13
λ4737 C12C12
λ4744 C12C13
λ4752 C13C13

PLATE X

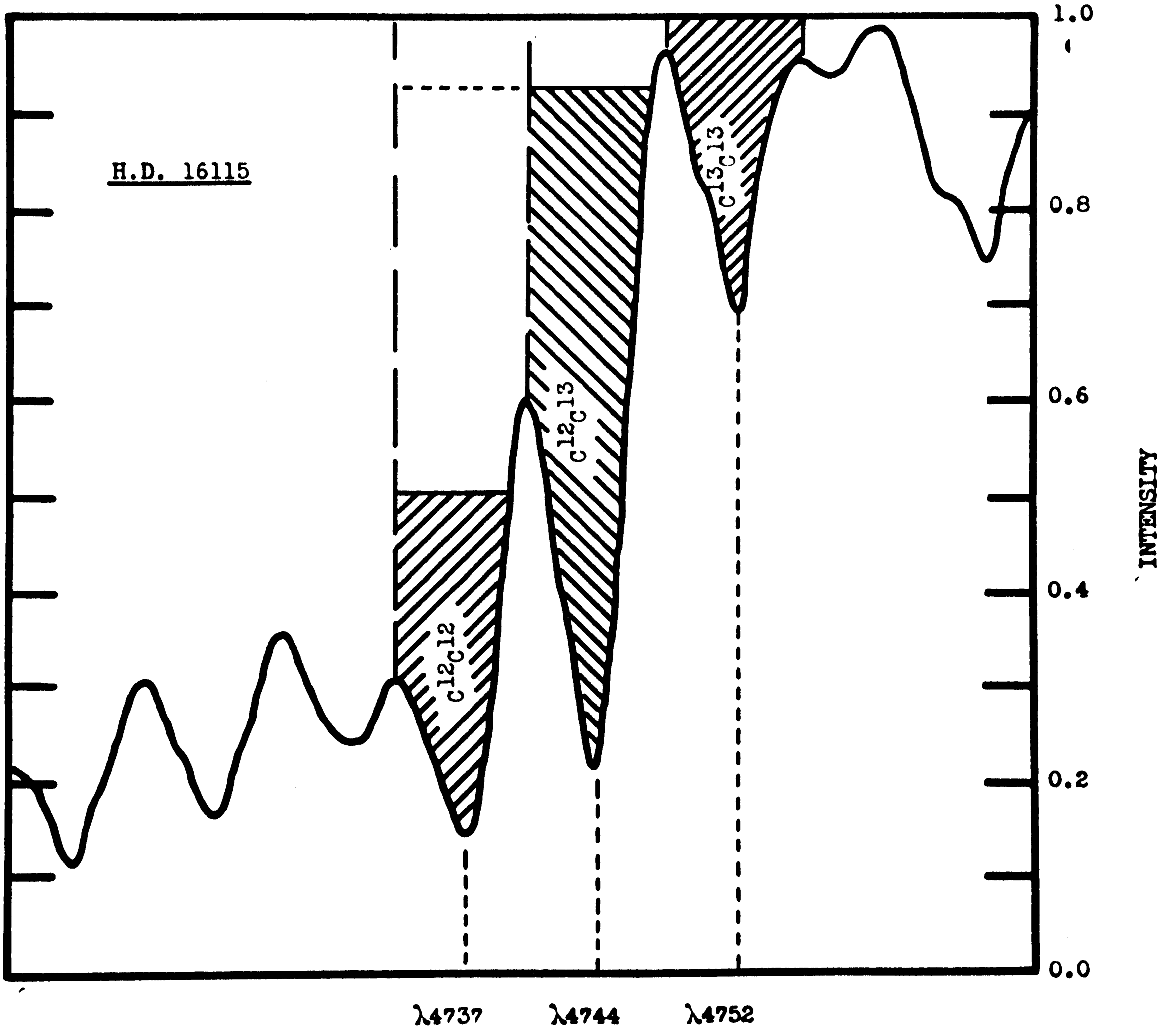


FIG. 8

value was found for the extraneous absorption over the corresponding region of the λ4752 band. The total measured intensities (equivalent widths) of the *P*-branch regions of the $C^{12}C^{13}$ and $C^{13}C^{13}$ bands were decreased by the appropriate one of the two mean corrections described. Probably the λ4737 main band suffers some similar blending between the limits λ4731 and λ4737·1. However, since the λ4737 C_2 band occurs in the spectra of all R-type stars the blending could not be directly evaluated. An examination of the intensity profiles of the spectra of the sun and of *a Bootis* over the λ4730–λ4752 region was made. In both these cases, the total intensities of absorption of atomic lines over the three ranges λ4730–λ4737, λ4737–λ4744, and λ4744–λ4751, were roughly equal. Adopting the reasonable assumption that this result would hold for the R-type stars, a blending correction of about the mean of those found for the two isotopic bands was applied to the intensities of the main $C^{12}C^{12}$ band. This correction reduced the intensities of the $C^{12}C^{12}$ bands by 0·50 equivalent Angstroms.

TABLE 2. INTENSITIES OF *P*-BRANCH REGIONS FOR THE MAIN AND ISOTOPIC 1,0 BANDS OF THE C_2 SWAN SYSTEM

Star		Equivalent width (in Angstroms) of *P*-branches between band origin and band head		
		λ4737 $C^{12}C^{12}$ band	λ4744 $C^{12}C^{13}$ band	λ4752 $C^{13}C^{13}$ band
1	H.D. 156074	1·95	1·20	0·25
2	209621	2·30	1·54	—
3	76396	2·45	⩽0·07	—
4	5223	2·68	1·57	—
5	182040	2·76	⩽0·20	—
6	223392	2·78	1·77	0·18
7	76846	3·37	2·16	0·41
8	197604	3·87	2·02	0·38
9	36972	4·46	2·62	0·65
10	56167	4·77	2·78	—
11	112869	4·99	⩽0·17	—
12	13826	5·35	1·71	0·49
13	187216	5·76	3·53	0·38
14	16115	6·32	3·22	0·54
15	1994	9·18	4·49	1·18
16	25408	Too much	5·37	2·25
17	79319	blending	7·50	3·44
18	10636	for	9·17	4·00
19	77234	significant	11·38	4·33
20	19557	measurement	Too much blending	4·59
21	52432		for significant measurement	5·25

The equivalent widths of the *P*-branch regions, band head to band origin, for the main and isotopic bands, determined as described above, are shown in Table 2. The twenty-one stars are listed in order of increasing strength of the main $C^{12}C^{12}$ bands.

THE ABUNDANCE RATIO OF C^{12} TO C^{13}

The most interesting application of the measurements of the relative intensities of the main and isotopic 1,0 C_2 bands is their use in attempting to deduce the relative abundance of the carbon isotopes for the different stellar atmospheres.

A number of troublesome factors which usually complicate problems of converting intensities of spectral lines into relative abundances are absent or have small effect in cases involving corresponding main and isotopic molecular bands. Such bands correspond to the same electronic and vibrational transitions and so, to a high degree of accuracy, have identical transition probabilities. Also, for the 1,0 Swan band of C_2, the lower state is the lowest vibrational level of the normal electronic state. Therefore, since the number and distribution of quantum states for the isotopic molecular species are similar except for a slight difference in scale, it is not necessary to make any assumptions about an effective temperature of the absorbing regions or about the character of the distribution of molecules among the states.

Various possible corrections in obtaining relative abundances from isotopic bands as observed in the laboratory have been discussed by J. L. Dunham[18] and by Elliott[19]. The corrections are in general small, except in cases where the bands investigated originate on high vibrational quantum states, or where, in emission, a peculiar excitation function operates, (e.g. active nitrogen), or where the equilibrium internuclear distances of the upper and lower states are markedly different. In such cases as these, corrections could aggregate about ten per cent. Dunham[18] took as one of his examples the 1,0 Swan band which is the subject of the present investigation (the band was referred to erroneously as the 0,1 band). He concluded that for it the corrections would be about one per cent, which is undoubtedly much smaller than the probable errors in the present work. Therefore, the derivation of relative abundances from the intensities of the bands can proceed directly. First, however, an attempt should be made to assess the effects of the curve of growth for the band-line absorption as produced in the stellar atmospheres.

For an atomic line in the solar spectrum, the initial straight section of the curve of growth where the intensity is determined by Doppler effect and is directly proportional to the number of absorbing atoms, extends up to about lines of equivalent width 0·05 A.[20]. For other stars[21], including giants, the Doppler part of the curve, without marked curvature, extends at least to the same intensity and in some cases to about 0·1 equivalent Angstroms. For the individual lines making up molecular bands in the solar spectrum, the recent work of Hunaerts[22] indicates that, in accordance with results for atomic lines, the Doppler part of the curve of growth reaches as far as lines of equivalent width 0·05 Angstroms.

Returning to the 1,0 Swan band at λ4737, laboratory data[23] show that the P branches from the band origin to the head and back as far as the origin include lines from $P(1)$ to $P(34)$. All these lines if completely resolved would be triplets, but the dispersion of a 21-foot grating shows them only as doublets. Therefore, the region of C_2 absorption measured in the spectra of the R-type stars is made up of at least 70 individual lines. In most of the stellar spectra under discussion, the integrated equivalent widths of this region are from about 2 to 6 Angstrom units, so a line of average intensity would have an equivalent width of from 0·02 to 0·09 Angstroms. Hence, at least to a first approximation, the individual lines may be assumed to fall on the Doppler portion of the curve of growth where the intensity varies directly as the number of absorbing molecules. Further, possible effects of crowding of the lines may be neglected, since only ratios of intensities will be used and the effect should be about the same for each band. To the extent that the above assumptions are justified we may proceed to obtain the abundance ratios of the main and isotopic molecules, and from these, of C^{12} to C^{13}, directly from the relative intensities of Table 2. Before doing so, two additional points should be mentioned. First, as an indication that the assumptions made are probably not radically in error, the discussion

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18 *Phys. Rev.*, **36**, 1553, 1930.
19 *Dissertation*, Utrecht, 1930; *Pr. Roy. Soc.*, **127**, 638, 1930;
Zs. f. Phys., **67**, 75, 1931; *Pr. Phys. Soc.*, London, **45**, 627, 1933.
20 See, *e. g.*, K. O. Wright, *Ap. J.*, **99**, 249, 1944.
21 See, *e.g.*, S. E. A. van Dijke, *Ap. J.*, **104**, 27, 1946.
J. L. Greenstein, *Ap. J.*, **107**, 151, 1948.
K. O. Wright, *These Publications*, **8**, 1, 1948.
22 *An. d'Ap.*, **10**, 237, 1947.
23 J. D. Shea, *Phys. Rev.*, **30**, 825, 1927.
R. C. Johnson, *Phil. Trans. Roy. Soc.*, A **226**, 157, 1927.

of intensity measurements on numerous molecular bands of C_2 and CN in three of the R-type spectra[24] may be cited. It indicated that for bands of moderate strength there was no definite evidence of having reached the flat transition portion of the curve of growth. Secondly, if the assumption made concerning the curve of growth should be considerably in error, while the numerical results given below would require some revision, the main conclusion that widely different C^{12} to C^{13} abundance ratios exist in the atmospheres of different R-type stars, would not be altered.

If the relative abundance of C^{12} to C^{13} is equal to a, then statistically the relative numbers of the molecular species $C^{12}C^{12}$: $C^{12}C^{13}$: $C^{13}C^{13}$ are as $a^2 : 2a : 1$. Therefore, assuming on the basis of the previous paragraph that intensity varies as the number of absorbing molecules, a may be found from any of the three intensity ratios:

$$\frac{I_{C^{12}C^{12}}}{I_{C^{12}C^{13}}} = \frac{a}{2} \; ; \qquad \frac{I_{C^{12}C^{13}}}{I_{C^{13}C^{13}}} = 2a \; ; \qquad \frac{I_{C^{12}C^{12}}}{I_{C^{13}C^{13}}} = a^2 \, .$$

For a given star, the three values of a so found are not, of course, independent. If the observational material and the assumptions involved in its reduction are sound, the three values of a found as above for any one star should agree. This is a necessary, but, obviously, not a sufficient condition for the correctness of the values derived.

The values of the abundance ratio of C^{12} to C^{13} obtained from the intensities listed in Table 2 are shown in Table 3. Where the data on intensities are complete, the abundance ratios from all three relationships are given. The figures in parentheses following values of the abundance ratio where there are three determinations for a star are the weights given the values of a in obtaining the mean value for the star, shown in the last column. The weights were arbitrarily assigned and depend mainly on judgment as to the accuracy with which the band intensities involved could be measured.

It is seen that of the twenty-one stars, there are three in which little evidence of C^{13} is present. For the three, the minimum values for the abundance ratio of C^{12} to C^{13} are 30, 60, and 70. The carbon in the atmospheres of these three stars could therefore possibly have an isotopic abundance ratio, $C^{12}C^{13}$ somewhat similar to that of terrestrial carbon, about 90. It is important to note that the three stars, H.D. 182040, H.D. 76396, and H.D. 112869 have by no means the weakest $C^{12}C^{12}$ bands among the twenty-one stars. Indeed, the 1,0 $C^{12}C^{12}$ band in the spectrum of H.D. 112869 is very strong. It may be remarked in passing that a fourth star similar to the above three in showing little if any evidence of C^{13} is H.D. 137613, type RO. The spectrum of this star has been photographed by Sanford, who has shown a reproduction of it[11]. The star is at declination −25°, too far south to be observed from Victoria with suitable dispersion.

The last six stars listed in Table 3 have such strong carbon bands that a significant isotopic abundance ratio cannot be obtained. Not only is the problem of measuring the intensities of the bands much more difficult but also lack of validity of the assumptions made concerning the curve of growth would become a distinct probability. Weaker bands of the Swan system, e.g., bands of the 0,2 λ6191 sequence, could be profitably studied for these six stars.

[24] A. McKellar and W. Buscombe, *These Publications*, **7**, 361, 1948.

TABLE 3. ABUNDANCE RATIO OF C^{12} TO C^{13}

	Star	Abundance ratio, *a*, of C^{12} to C^{13} from $I_{C^{12}C^{12}}/I_{C^{12}C^{13}}$	from $I_{C^{12}C^{13}}/I_{C^{13}C^{13}}$	from $I_{C^{12}C^{12}}/I_{C^{13}C^{13}}$	Mean *a*
1	H.D. 156074	3·2 (3)	2·4 (1)	2·8 (1)	3·0
2	209621	3·0	—	—	3·0
3	76396	⩾ 70	—	—	⩾ 70
4	5223	3·4	—	—	3·4
5	182040	⩾ 30	—	—	⩾ 30
6	223392	3·1 (3)	4·9 (1)	3·9 (1)	3·6
7	76846	3·1 (3)	2·6 (1)	2·9 (1)	3·0
8	197604	3·8 (3)	2·7 (1)	3·2 (1)	3·5
9	36972	3·4 (3)	2·0 (1)	2·6 (1)	3·0
10	56167	3·4	—	—	3·4
11	112869	⩾ 60	—	—	⩾ 60
12	13826	6·3 (3)	1·7 (1)	3·3 (1)	4·8
13	187216	3·3 (3)	4·6 (1)	3·9 (1)	3·7
14	16115	3·9 (1)	3·0 (1)	3·4 (1)	3·4
15	1994	4·1 (1)	1·9 (1)	2·8 (1)	2·9
16	25408	Bands too strong to obtain a significant result			
17	79319				
18	10636				
19	77234				
20	19557				
21	52432				

The remaining twelve stars show an unexpected uniformity in their values of the C^{12}/C^{13} abundance ratio. Also, the results from the three intensity ratios agree, on the whole, fairly well. The mean value for the twelve stars is 3·4 with a standard deviation of 0·16.

Further remarks may be made at this point on the assumption regarding the curve of growth. If the weak bands were on the Doppler portion and stronger ones on the transition portion of the curve, there should be two effects evident in Table 3. The stronger the band, the greater should be the degree of invalidity of the assumption and since the stars in Table 3 are listed in order of increasing strength of C_2 bands, there should be a progressive decrease in the values of *a* (assuming of course that for the twelve stars considered, *a* is actually roughly constant). No such trend is present down to star number 15. For stars 16 to 19, *a* values from the two isotopic band intensities are 1·2; 1·1; 1·1, and 1·3. It is felt that the assumption made breaks down for the last six stars. Secondly, since the main band is always strongest, the $C^{12}C^{13}$ band next and the $C^{13}C^{13}$ band weakest, a failure of our assumption, while making all three calculated values of *a* smaller than the true value, should probably affect the stronger bands most. The effect would be to make *a* from the intensity of the $C^{12}C^{12}$ band (first and third columns) smaller than the value in the middle column. The means of the three columns are 3·7, 2·9, and 3·2, respectively. The differences are appreciable but opposite to the suggested direction. It would thus appear that the assumption made is not radically wrong, but it might be safest to consider all the values of *a* found as minimum values.

Rough checks on the results of Table 3 have been carried out in two ways. The first was an examination of the ultra-violet spectra of the two stars H.D. 156074 and H.D. 76396. For H.D. 156074 a subsidiary band head occurs at λ3596, 5·5 A. to the red of the main 1,0 C^{12} N^{14} head of the violet CN system at λ3590. This subsidiary head is at the calculated position of the isotopic C^{13} N^{14} band head. For H.D. 76396 no such isotopic head accompanies the main one. This observation is in accord with the C_2 bands in the spectra of these stars for H.D. 156074 shows a C^{12} C^{13} band while H.D. 76396 is one of the three stars showing little trace of C^{13}. Intensity measurements on the *P* branches of the CN bands yielded results in general harmony with those from the 1,0 C_2 Swan bands.

The second check was made by measuring the intensities of the main and isotopic 1,0 Swan bands of C_2 from two-prism spectrograms of H.D. 156074 giving a dispersion of 21 A. per mm. at λ4740. While the actual equivalent widths were greater than found from the single-prism spectrograms, the relative values did not differ much, and gave a mean C^{12} to C^{13} abundance ratio of 2·9 in good accord with the value 3·0 in Table 3.

It does not seem probable that any curve-of-growth phenomenon could account for the disparity in the C^{12} to C^{13} abundance ratio between the three stars showing very little evidence of C^{13} and the group giving a mean abundance ratio of about 3. No other physical explanation of the difference is apparent. Therefore, unless and until some more acceptable explanation is put forward, we interpret the present results as evidence that real differences in the ratio of abundance of the carbon isotopes exist in the different stellar atmospheres.

It is not thought that the approximate constancy of the abundance ratio, *a*, for the twelve stars arises from any selective effect present in the observations or entirely from the method of treating the data. While future results obtained from spectrograms of higher dispersion may change the numerical values obtained in this investigation, it seems possible meanwhile to classify most of the R-stars into two groups, one with the ratio of C^{12} to C^{13} high, say at least 50 or more, and the other with the ratio low, about 3. If the two groups are thus to be distinguished in reality, it is a matter of much interest. It probably is connected with the origin or evolution of the stars and particularly with the nuclear reactions that have gone on within them.

An attempt was made to relate the carbon isotopic abundance ratio with various other observable factors such as position in the sky, radial velocity, other spectral peculiarity, etc. However, no significant correlations were found. As an example, we may consider the small group of seven R-type stars known to have very high negative radial velocities (−100 to −300 km/sec.) and to have unusually strong absorption bands of CH. Their high velocities may indicate membership in Population II. These stars have been designated by Keenan and Morgan[25] as the CH stars and have been studied by Keenan[26]. One of the CH stars (H.D. 112869) is among the three showing no C^{13} while others (H.D. 5223 and H.D. 209621) are among the stars giving a C^{12} to C^{13} ratio about 3.

In connection with one possible explanation, described in the next section, of the existence of two groups of stars having different carbon isotopic abundances, any intermediate cases whould be of importance. It is of interest to examine the twelve stars

[25] *Ap. J.*, **94**, 501, 1941.
[26] *Ap. J.*, **96**, 101, 1942.

giving a mean ratio about 3 to find any that might fall in such a category. The most likely star would appear to be H.D. 13826, V *Arietis*, for which $a = 4 \cdot 8$. Its mean value of a is highest in Table 3, except of course for the three stars showing little C^{13}. Also, the appearance of its spectrum on Plate IX and the corresponding intensity profile in Fig. 5 are suggestive. They show that while the C^{12} C^{12} band is markedly stronger than for nearly all the stars preceding V *Arietis* on Plates VIII and IX, the C^{12} C^{13} band is no stronger and probably weaker. The evidence is therefore quite convincing that V *Arietis* is an intermediate case.

DISCUSSION

In the previous section, data were presented indicating that there may exist two groups among the R-type stars, one having a C^{12} C^{13} abundance ratio of, say, 50 or more, and the other a ratio of about 3. An explanation of the co-existence of such sub-divisions would be of much interest and of possible considerable significance. Two possible types of explanation are described. The first is related to a theory of the origin of the chemical elements and the second to a possible chain of events in the operation of the carbon-nitrogen energy-producing cycle.

Recently, Klein, Beskow and Treffenberg have published a number of papers[27] on the origin and abundance distribution of the chemical elements. They consider aggregations of matter with very dense cores only a few kilometres in diameter and in thermal equilibrium at $kT = 1$ Mev. These may be called stellar models, but as the authors suggest, are better taken as the origins of existing stars. The different models are obtained by varying the neutron potential in the centre of the star up to the critical value of $5 \cdot 6$ Mev. where matter is supposed to condense to a close-packed core with the density of an atomic nucleus, and then by varying the radius of this core. A number of their models give relative abundances of the elements in fair accord with the Goldschmidt distribution[28] for terrestrial matter, which also fits reasonably well with stellar, nebular, and other sources. Furthermore, the various models yield not only different absolute abundances of, say carbon, but different relative abundances of C^{12} to C^{13}. Among the models giving good absolute abundances for carbon, the C^{12} to C^{13} ratio varies between limits of about 15 and 55. The models having a close-packed core of radius between 5 and 7 km. are especially sensitive both to the absolute and relative abundances of C^{12} and C^{13}. It is interesting and possibly significant that the best agreement with the Goldschmidt distribution is also found in this range of values of the core radius.

The range in C^{12} to C^{13} abundance given by the above models is not as great as found for the R-type stars, and does not reach the terrestrial value of 90. Nevertheless, the variation from 15 to 55 is considerable, and at the present stage of investigation, the final word has not been said on either the observational or theoretical side. For example, the influence of a variation of the equilibrium temperature has not yet been carefully studied[29] and it seems possible that a temperature below $kT = 1$ Mev. might give results more in accord with observation. Results of further calculations of the above nature will be received with interest.

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[27] *Ark. f. Mat. Ast. och Fys.* 33B, No. 1, 1946; **34A**, No. 13, 1947; **34A**, No. 17, 1947; **34A**, No. 19, 1947.

[28] *Geochemische Verteilungsgesetze der Elemente, IX, Die Mengenverhaltnisse der Elemente und der Atom-Arten*, Oslo, 1938.

[29] T. Beskow, *Private Communication.*

The second type of hypothesis deals with the evolutionary process within stellar interiors rather than the origin of the chemical elements. It is due to Professor E. Fermi and arose from a discussion which the writer was privileged to have with him at the University of Washington, Seattle, in the summer of 1947. It is a pleasure to acknowledge with thanks both the kind interest of Professor Fermi and his permission to outline the suggested explanation here.

It may be recalled that, so far as is known, all the stars of types R and N are giants. The later R-stars and the N-stars are definitely red while the earlier R-stars have colours like later G- and K-type stars. Following Gamow[30], we assume that the evolutionary chain of events in the energy production in the interiors of red giant stars proceeds in a series of steps of gravitational contraction and the disruption under proton bombardment of certain light easily disintegrated atomic nuclei. First, gravitational contraction takes place until the temperature is sufficient at the centre of the star to cause proton-deuteron interaction. This reaction provides the energy until all the deuterium is used up. Then further contraction takes place until the temperature is high enough to provide the protons with sufficient energy to disintegrate lithium nuclei. Then further contractions occur and the "burning up" successively of beryllium and boron. Finally, when these elements are used up, contraction raises the internal temperature sufficiently (to around 2×10^{7}°K) to start the proton-carbon reaction which initiates the carbon-nitrogen cycle* described by Bethe. When the carbon-nitrogen cycle has become established, the relative abundances of C^{12}, C^{13}, N^{14}, and N^{15} should be determined by their lifetimes under proton bombardment. The calculated lifetimes, as given by Bethe[31] in 1940 (they may have somewhat different values determined from more recent work in the nuclear physics laboratories) are,

C^{12}—$2{\cdot}5 \times 10^{6}$ years
C^{13}—5×10^{4} years
N^{14}—4×10^{6} years
N^{15}—20 years

These figures are for conditions assumed at the centre of the sun, namely, density, $\rho = 80$ gm/cm.^{3}; hydrogen content, 35 per cent; temperature $= 2 \times 10^{7}$ degrees. Bethe states that the lifetimes given could all be wrong by a factor of 3 either way. They indicate that C^{13} would capture slow protons 50 times as easily as C^{12}, but experimental data[32] of that time (1939) gave the ratio as 70. This figure agrees reasonably well with the observed terrestrial relative abundance of C^{12} to C^{13}, which is 90.

[30] See, *e. g.*, *Nature*, **144**, 575, 1939.
[31] *Ap. J.*, **92**, 118, 1940.
[32] H. A. Bethe, *Phys. Rev.*, **55**, 434, 1939.

*The equations representing the reactions of the carbon-nitrogen cycle are:

$$C^{12} + H^{1} = N^{13}$$
$$N^{13} = C^{13} + e^{+}$$
$$C^{13} + H^{1} = N^{14}$$
$$N^{14} + H^{1} = O^{15}$$
$$O^{15} = N^{15} + e^{+}$$
$$N^{15} + H^{1} = C^{12} + He^{4}$$

The net result of the cycle is seen to be the conversion of four protons into a helium nucleus. The radioactive nuclei N^{13} and O^{15} decay effectively instantaneously into C^{13} and N^{15}, respectively, with the emission of a positive electron, and the lifetimes of the other reactions are as given in the text above.

We now make two assumptions: (1) Suppose that there is sufficient mixing throughout a star, so that its atmosphere indicates at least approximately the internal constitution. There is some indirect observational evidence that this might be so; for example, the low stellar atmospheric abundances of the readily disrupted elements D, Li, Be, and B. From the theoretical side, there have been thought to exist arguments against such mixing, but according to very recent work of Hoyle[33], violent convection currents should exist within stars and keep the matter well mixed; (2) Suppose that in the "original matter" of which the stars were made the C^{12} to C^{13} ratio was fairly low, say about 3. Then this abundance ratio would remain at 3 through the red giant stages until the carbon-nitrogen cycle started. The higher cross-section of C^{13} compared to C^{12} for protons would then cause the ratio of C^{12} to C^{13} to increase as the cycle developed and to reach the final value of about 70 when the carbon-nitrogen cycle had finally reached equilibrium. Hence, there would be the beginning and end points, where the C^{12} to C^{13} ratio would be about 3 and about 70, respectively, as the observations indicate. There would be a stage while the carbon-nitrogen cycle was becoming established, where the abundance ratio would be undergoing change from the low to high value. The relative length of the transition period would probably be short compared with the red giant stage and the final stage, because of the extremely high temperature coefficient (up to T^{18}) of the nuclear reactions. Therefore, there should not on the average be many stars in the transition stage, and the case of V *Arietis*, noted in the preceding section as a possible intermediate case, might be of special interest.

A quantitative theoretical discussion of the above attractive hypothesis on the basis of most recent data on nuclear physics, including the estimation of a time-scale, etc., would be most desirable. It is hoped that some theoretical physicist may undertake this task. If, on the basis of such future developments, the hypothesis is found to stand up well, the observed ratio of C^{12} to C^{13} might give valuable information on the stages of evolution of individual stars.

To return briefly to the observational aspects of the problem, what tests could be made? One consequence of the theory is that in the early phases of the establishment of the carbon-nitrogen cycle, C^{13} is being converted much more rapidly into N^{14} than N^{14} into N^{15} so that temporarily there would be an excess of N^{14}. Whether this could be observed would depend upon the relative abundance of N^{14} to C^{13} in the "original matter". The same sort of argument would seem applicable to the N^{15} to C^{12} stage of the cycle. If, as would appear unlikely, the original N^{15} to C^{12} abundance ratio were appreciable, the onset of the Bethe cycle would produce a temporarily high abundance of C^{12}. As another consequence, it would be expected that the N-type giants would not yet have reached the carbon-nitrogen cycle stage, and so should all show C^{13}. In fact, an examination of our spectrograms of twenty-five N-type stars shows C^{12} C^{13} bands in all.

One might expect the absolute magnitudes of the individual R-type stars to yield information on whether or not the hypothesis suggested by Fermi is a likely one. The carbon-nitrogen cycle is strictly applicable only to stars of the main sequence having central temperatures and pressures of the order of those of the sun. The course of evolution

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[33] Symposium on "*Abundances of Elements,*" I.A.U. Meeting, Zurich, 1948, as reported by O. Struve in *Pop. Ast.*, **56**, 401, 1948.

described above suggests that in the stars showing a high C^{12}/C^{13} ratio this cycle has become established and that therefore they should be more dwarfish than the majority of the R-type stars. The mean absolute magnitude $-0{\cdot}50 \pm 0{\cdot}20$ found by R. E. Wilson[34] for R-type stars should be substantially correct. Data on the absolute magnitudes of individual R stars, are, however, scanty. All the information found is shown in Table 4. There are trigonometric parallaxes for three stars, including two independent values for one of them. For four stars, including two of those with trigonometric parallaxes Sanford has estimated absolute magnitudes from the measured intensities of the interstellar sodium D-lines occurring in their spectra. Little reliance can be placed in the trigonometric parallaxes, as may be seen from the case of H.D. 5223 where the two independent values differ so greatly. The uncertainties of measuring the distances of individual stars

TABLE 4. ABSOLUTE MAGNITUDES OF INDIVIDUAL R-TYPE STARS

Star	Visual Magnitude	Spectral Type	Trigonometric Parallax (seconds of arc)	Absolute Magnitude
H.D. 5223	8·8	R3	+·045 ± ·010 *	+7·1
			−·005 ± ·006 †	(?)
				+2·2 §
H.D. 13826	8·3–9·0	R5		−1·7 §
H.D. 137613	7·4	R0		−1·0 §
H.D. 197604	9·8	R4	+·013 ± ·011 *	+5·4
H.D. 209621	8·8	R3	+·010 ± ·005 ‡	+3·8
				+0·4 §

* F. Schlesinger, *Catalogue of Stellar Parallaxes*, Yale University Observatory, 1936.
† A. van Maanen, *Ap. J.*, **87**, 424, 1938; *Mt. Wilson Cont.*, No. 590.
§ R. F. Sanford, *Ap. J.*, **99**, 145, 1944; *Mt. Wilson Cont.*, No. 689.
‡ A. van Maanen, *Astron. Jour.*, **50**, 41, 1942.

from intensities of interstellar lines, arising from the irregularities in the distribution of interstellar material, are well known. The data of Table 4, taken as they are, indicate that H.D. 137613 (the fourth star having a high C^{12}/C^{13} ratio) and H.D. 13826 (the possible intermediate case, V *Arietis*) are least dwarfish of the five stars. Thus, no support is given Fermi's hypothesis. On the other hand, the data are so meagre that they cannot be taken as ruling it out. It would be of much interest to obtain trigonometric parallaxes for the three stars, H.D. 76396, H.D. 112869, and H.D. 182040, showing the high C^{12}/C^{13} abundance ratio.

[34] *Ap. J.*, **90**, 486, 1939.

DOMINION ASTROPHYSICAL OBSERVATORY,
Victoria, B.C.
September, 1948.