CARBON ABUNDANCE IN WC STARS

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A specific feature of WC stars is the presence in their spectra of strong subordinate series lines of carbon ions arising in transitions between comparatively high-lying states. The intensities of these lines suggest that carbon abundance must be comparatively high in WC star envelopes because subordinate series lines are already nearly transparent to radiation (escape probability coefficients β_{ik} are close to unity) and their intensities strongly depend on the abundance of C($J_{ki} \propto N_k$). The resonance lines of carbon ions and the lines arising in the permitted transitions between the low-lying energy levels are in a wide abundance interval not very sensitive to abundance due to the fact that $\beta_{ik} << 1$ for these transitions ($J_{ki} \propto N_k/N_i$). For 3 WC stars (HD 165763 (WC5), HD 192103 (WC8) and HD 164270 (WC9)) we carried out the same kind of model-fitting study as for the WN stars (reported earlier). We used the same empirical models, that is we assumed that also for them the wind reaches the terminal velocity at $R \simeq 2\ R_o$ (v = const for $R \geq 2\ R_o$) and that $T_e(R \geq 2\ R_o) = T_e^{II} = 0.6\ T_*$, where T_* denotes the core temperature. We took into account the ions (atoms) of He, H and C for determining the ionization structure in the envelope.

For the study of the line spectra of He II, He I and H I we also used (as in the case of WN stars) the graphical method to search for blend-free lines with the coefficients $\overline{b_k \beta_{ik}} \simeq 1$ (b_k: the Menzel coefficient, β_{ik}: the line escape probability coefficient). Figure 1 presents the corresponding data for the (n-4) series of He II and (n-2) series of H I of HD 192103 (WC8) and HD 164270 (WC9). In the case of HD 165763 the blending of lines is more severe, and from the data available it was not possible to establish the amount of energy emitted in the hydrogen lines. For determining the carbon abundance we used the lines C IV λ 5474, 8860, C III λ 4070, 8664 and C II λ 4267. Assuming that $\beta_{ik} \simeq 1$, we found the coefficients b_k from the following relationship

$$b_k \simeq \frac{A_{ck} + A_{di}(k)\left(1 + \frac{c^3}{8\pi\ h\nu^3}\rho\nu\right)\beta' + \frac{(b_k+1)}{2}\sum_{i>k} z_i^o A_{ik}}{z_k^o \sum_{i<k} A_{ki} + A_{di}(k)\frac{c^3}{8\pi\ h\nu^3}\rho\nu \exp\left(\frac{E_{1;2}^{(+)}}{k\ T_e}\right)\beta'} \qquad (1)$$

C. W. H. de Loore and A. J. Willis (eds.), Wolf-Rayet Stars: Observations, Physics, Evolution, 131–134.

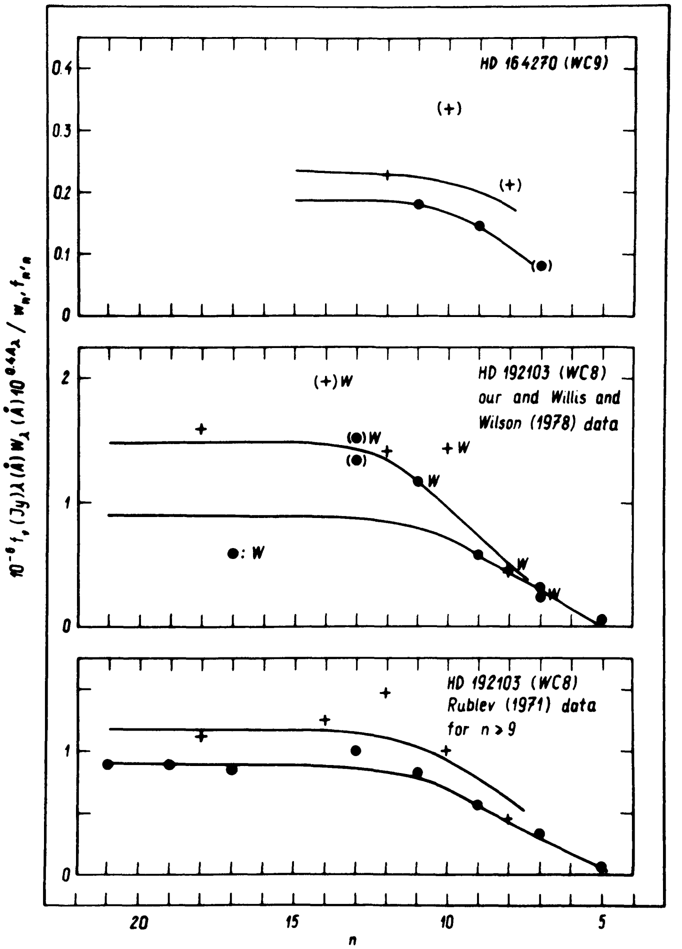

Fig. 1. The dependence of reduced intensities on the upper level principal quantum number n. For the blend-free lines of certain series (n'= const) $J'_{nn'} \propto b_n \beta_{n'n} \exp(J_n/k\, T_e)$.
● : the Pickering (odd n) series
+ : the Pickering (even n) + Balmer series
In brackets are given the blended lines. Steady line denotes the adopted run of blend-free reduced intensities.

where A_{ck} is the spontaneous radiative recombination coefficient, $A_{di}(k)$ is the spontaneous dielectronic recombination coefficient, $\rho\nu$ is the radiation density at the frequency corresponding to the transition from doubly excited state into singly excited state (the corresponding energy difference is denoted by $E^{(+)}_{1;2}$ and β' is the escape probability coefficient for this transition.

Table 1. The parameters of WC stars

	HD 165763 (WC5)	HD 192103 (WC8)	HD 164270 (WC9)
E_{B-V}	0.29$^{(1)}$	0.38$^{(1)}$	0.53$^{(2)}$
r(kpc)(3)	2.14	2.52	2.08
v_∞(km/s)	3000	1500	1000
v_∞/v_o (4)	3	3	3
T_*(K)	60000	50000	40000
T_e^{I}(K)	100000	100000	100000
T_e^{II}(K)	36000	30000	24000
$R_o(R_\odot)$	4.69	4.79	6.37
$N(He)_{2R_o}$ (cm^{-3})	$4.81.10^{11}$	$1.03.10^{12}$	$2.59.10^{11}$
He/H	-	$\gtrsim$ 5	$\gtrsim$ 8
C/He	$\simeq$ 0.2	$\simeq$ 0.1	$\simeq$ 0.2
$\dot{M}(M_\odot/yr)$	$1.33.10^{-4}$	$1.22.10^{-4}$	$4.42.10^{-5}$
$\dot{M}/\dot{M}_1$ (5)	76.8	69.7	23.3

Sources for E_{B-V} : (1) - our estimations through the λ 2200extinction bump nulling method from the TD1 UV spectrophotometric data (Willis and Wilson, 1978);

(2) - E_{B-V} has been found from the $(b-v)_o$ scale. We adopted the value $(b-v)_o$ = -0.41 which has been derived by assuming that for HD 136488 (WC9) the value of E_{B-V} is equal to 0.66 (the mean of the data obtained by using the previous value of $(b-v)_o$ = -0.32 (L.F. Smith, 1968) and from the paper by van der Hucht et al. (1979).

(3) - r was estimated from the scaling rule $r = \max\{r(M_V).r(E_{B-V})\}$.

(4) - v_∞ and v_o were estimated from the positions of the minima of the violet-displaced absorption components.

(5) - $\dot{M}_1 = L/c\, v_\infty$, L was found from the formula $L = 4\pi^2 R_o^2 \sigma T_*^4$.

https://doi.org/10.1017/S0074180900028801 Published online by Cambridge University Press

The theoretical intensities found with b_k derived from Formula (1) and with $\beta_{ik} = 1$ ought to predict the observed intensities with the factor of uncertainty equal to about 2-3. For C III and C II we made the calculations of b_k with the help of Formula (1) at three different assumptions about the values of β' and $\rho\nu$. In the first case we assumed that $\beta' = 1$ and $\rho\nu = 4\pi B\nu(T_e)/c$. In the second variant we proposed that $\beta' = 0$ and in the third variant $\beta' = 1$ and $\rho\nu = 0$. The differences between different variants are not great. We used the variant I. The equivalent widths of emission lines were taken from the papers: H.Smith (1955)(HD 164270); McDonald (1947)(HD 165763); Rublev (1971), Willis and Wilson (1978), Nugis (1974)(HD 192103); Kuhi (1968)(near IR lines). The parameters found for 3 WC stars from our model-fitting study are presented in Table 1 (the lines 5-11). From our study it followed that carbon abundance is high in the envelopes of all 3 WC stars studied: N(C)/N(He $\simeq$ 0.1-0.2. Hydrogen seems to be present in the envelopes of the stars HD 192103 and HD 164270 (it was not possible to make individual estimates for HD 165763) and N(H)/N(He) $\lesssim$ 0.2. It must be added that our chemical composition estimates are not sensitive to model predictions.

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