THE SPECTRA OF THE WOLF-RAYET STARS IN THE REGION λλ 6500–8800*

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ABSTRACT

The spectra of seven Wolf-Rayet stars have been observed in the region λλ 6500–8800. For the identifications, tables of predicted lines of *C* II–IV, *O* II–VI, and *Si* III and IV were prepared. All strong emission lines are satisfactorily explained in the WC sequence; in the WN sequence, a fairly strong complex emission near λ 8240 remains unidentified.

No spectroscopic information on Wolf-Rayet stars is available in the near-infrared region.[1] Spectrograms in this region were obtained in June, 1949, for seven Wolf-Rayet objects, using the fast plane-grating spectrograph at the prime focus of the McDonald reflector. The linear dispersion is 370 A/mm at λ 6600, 345 A/mm at λ 7500, and 312 A/mm at λ 8500. The I-N emulsion used was hypersensitized with ammonia; the exposures ranged from 20 minutes to 4 hours. Fourteen spectrograms of good quality were obtained, seven of WC objects and seven of WN objects. The list of the observed stars is given in Table 1.

TABLE 1

WOLF-RAYET STARS OBSERVED IN THE NEAR-INFRARED REGION

Carbon sequence	HD 184738 (WC8 + nebula) (2 exp.)
	HD 164270 (WC8) (2 exp.)
	HD 168206 (WC7) (2 exp.)
	HD 192103 (WC7) (1 exp.)
Nitrogen sequence	HD 151932 (WN6+) (2 exp.)
	HD 192163 (WN6) (3 exp.)
	HD 193077 (WN5) (2 exp.)

Of these objects, HD 168206 is a binary,[2] while HD 193077 is a suspected binary.[3] From Hiltner's period, the phase for our spectrograms of HD 168206 would be about 14.4 days, which would correspond to velocities of the order of +330 km/sec for *He* II emission, +125 km/sec for *C* III and *C* IV emission, and −10 km/sec for *H* absorption. However, no correction has been entered in our list of wave lengths, although we usually find the measured wave lengths of HD 168206 to be higher than those of the other WC objects. The list of stars observed does not represent the two sequences as well as we desired: adverse observing conditions prevented us from extending the investigation to a greater number of objects. It is hoped that the work may be pursued at some later time.

The spectrograms are reproduced in Figures 1 and 2. It is readily apparent that the WC stars are much richer in infrared lines than are the WN objects. The difficulties encountered in measuring Wolf-Rayet spectra in the usual spectral region have also been encountered in the infrared. In addition, great difficulty arose in relation to the identifica-

* *Contributions from the McDonald Observatory, University of Texas*, No. 188.

[1] C. S. Beals (*Pub. Dom. Ap. Obs., Victoria*, **4**, 271, 1930) observed five lines beyond *Hα*, to λ 7117 (Table 1, p. 277).

[2] W. A. Hiltner, *Ap. J.*, **102**, 492, 1945.

[3] Hiltner, *ibid.*, **101**, 356, 1945.

Table 2

Carbon Sequence

Identification			HD 184738 (WC8)		HD 164270 (WC8)		HD 168206 (WC7)		HD 192103 (WC7)	
Element	λ	Designation	Int	λ	Int	λ	Int	λ	Int	λ
Hα	*6562.8	$2^2P^o-3^2D$	12	62.5					20	65.4
He II	6560.1	$4^2F^o-6^2G$			15	81.8	8	77.9		
C II	*6578.0	$3s^2S_{\frac{1}{2}}-3p^2P^o_{1\frac{1}{2}}$							10	96.4
C II	6582.8	$3s^2S_{\frac{1}{2}}-3p^2P^o_{\frac{1}{2}}$								
C IV	6591.9	$6s^2S_{\frac{1}{2}}-7p^2P^o_{\frac{1}{2},\,1\frac{1}{2}}$								
C III	6617.6	$5p^3D_3-6d^3D^o_3$	1?	7.7	1s?	13.8				
O IV	6632.1	$5d^2F^o_{2\frac{1}{2}}-3d'''^2F_{2\frac{1}{2}}$							1?	31.8
(O II	6627.7	$3d^2P_{1\frac{1}{2}}-4p^2P^o_{1\frac{1}{2}}$)								
He I	6678.1	$2\,{}^1P^o_1-3\,{}^1D_2$	3	78.7	4	80.2			3	78.7
(O V	6685.3	$4d\,{}^1P^o_1-7d\,{}^1D_2$)								
C III	*6744.2	$3s^3P^o-3p^3D$	2	30.1	8	36.5	4	47.3	15	40.8
C III	6730.7									
C III	6727.1									
C III	6742.2									
(C II	6750.2	$3p^4D-3d^4D^o$)								
(C II	6738.4									
(O III	6737.1	$4d^3D^o_3-3s'^3D_3$)								
(O III	6743.0	$3d^3P_2-6d^3D^o_3$)								
(O IV	6745.8	$3s''^4P_{2\frac{1}{2}}-4d^4D^o_{3\frac{1}{2}}$)								
C II	6783.7	$3s^4P^o_{2\frac{1}{2}}-3p^4D_{3\frac{1}{2}}$	3	80.7	8	85.0			2	82.1
C II	6779.7	$3s^4P^o_{1\frac{1}{2}}-3p^4D_{2\frac{1}{2}}$								
(C III	6779.4	$3d^3P^o-6s^3S$)								
(C III	6791.5									
(C III	6798.2									

Table 2 (continued)

Identification			HD 184738 (WC8)		HD 164270 (WC8)		HD 168206 (WC7)		HD 192103 (WC7)	
Element	λ	Designation	Int	λ	Int	λ	Int	λ	Int	λ
C III	6803.6	$9d\,^3D_3-4d\,^3P^o_2$					1?	10.7		
O IV	6817.5	$3p''\,^2D^o_{2\frac{1}{2}}-3d''\,^2F_{3\frac{1}{2}}$								
(O III	*6847.8	$4p\,^3D_1-4d'\,P^o_1$)			1?	53.5				
C III	*6857.3	$3p\,^3D-3d\,^3D^o$							2s	61.4
C III	6862.9									
C III	6871.7									
C III	*6881.9	$3p\,^3P-5p\,^3P^o$			1?	00.0			4	94.6
C III	6899.4									
(OV	6888.9	$3d\,^3P^o_2-4s\,^3S_1$)								
(O II	6895.3	$3d\,^4F-4p\,^4D^o$)								
(O II	6906.6									
(O III	6952.8	$4s\,^1P^o_1-4p\,^1S_o$)			0	46.2			0	38.3
(O IV	6931.4	$3s\,^2P^o_{\frac{1}{2}}-3p\,^2P_{\frac{1}{2}}$)								
(C II	6959.3	$4p\,^4P_{2\frac{1}{2}}-5d\,^4D^o_{3\frac{1}{2}}$)			1-0?	69.4			1	72.1
C III	7036.9	$3s\,^1P^o_1-4d\,^1D_2$	5	35.6	6	33.1			5	25.6
							3	53.5		
He I	*7065.2	$2\,^3P^o_{2,1}-3\,^3S_1$	4	64.4	8	62.3			15	60.2
(C III	7047.8	$5p\,^3P_2-6d\,^3P^o_2$)								
(C II	7063.4	$3p\,^4S-3d\,^4P^o$)								
(C II	7052.9									

Table 2 (continued)

Identification			HD 184738 (WC8)		HD 164270 (WC8)		HD 168206 (WC7)		HD 192103 (WC7)	
Element	λ	Designation	Int	λ	Int	λ	Int	λ	Int	λ
(O III	*7109.1	$4s^3P^o_1-4p^1D_2$)	2	8.2	3	10.5			2?	4.4
(O II	7110.5	$3d^2D_{2\frac{1}{2}}-4p^2P^o_{1\frac{1}{2}}$)								
(C II	7119.4									
(C II	7115.1	$3p^4D-3d^4F^o$)								
(C II	7112.4						2	26.9		
(C I	7118.5	$3p^3D-4d^3F^o$)								
C III	*7136.8	$5p^3P_2-6d^3D^o_3$	1-2	33.0	2	29.3			3	38.8
C III	7158.4	$3d^1D^o_2-5d^1D_2$			1	56.4				
(O IV	7152.6	$3d'^2F^o_{3\frac{1}{2}}-4p^2D_{2\frac{1}{2}}$)								
(O III	7189.7	$4p^3D_3-4d^3P^o_2$)			1	84.0			0	79.5
C II	*7231.1	$3^2P^o_{\frac{1}{2}}-3^2D_{1\frac{1}{2}}$	8	29.1						
C III	7210.4	$5p^3P^o_2-6d^3D_3$			20	31.5	10	33.9	12	34.2
C II	*7236.2	$3^2P^o_{1\frac{1}{2}}-3^2D_{2\frac{1}{2}}$	8	34.4						
(O III	7243.3	$3d^3F_2-6d^3D^o_3$)								
(O III	7249.8	$4s^3P^o_2-4p'D_2$)								
			0	71.7						
He I	*7281.3	$2'P^o_1-3'S_0$			2	83.2			1?	88.8
(O II	7280.9	$3d^2D_{2\frac{1}{2}}-4p^2D^o_{2\frac{1}{2}}$)	0	94.8						
(O III	7294.3	$3d^3F_3-6d^3D^o_3$)								
O III	7317.6	$5s^3P^o_2-3d^3D_3$							0	23.0
C III	7352.7	$3p'D_2-3d'P^o_1$							0	45.6
(O III	7343.8	$5s^3P^o_2-3d^3D_2$)								
(O V	7359.6	$4s'P^o_1-4p'D_2$)								

Table 2 (continued)

Identification			HD 184738 (WC8)		HD 164270 (WC8)		HD 168206 (WC7)		HD 192103 (WC7)	
Element	λ	Designation	Int	λ	Int	λ	Int	λ	Int	λ
C IV	*7380.2	$6p^2P^o_{\frac{1}{2},1\frac{1}{2}}-7d^2D_{1\frac{1}{2},2\frac{1}{2}}$	1	81.1	1?	70.7	1	90.8	8	78.9
(O II	7369.3	$3d^4P_{2\frac{1}{2}}-4p^4D^o_{3\frac{1}{2}}$)								
(O III	7366.1	$3d^3F_4-6d^3D^o_3$)								
O IV	7418.0	$6d^2D_{2\frac{1}{2}}-7f^2F^o_{3\frac{1}{2}}$	1-0	20.0					3	25.8
O V	7437.3	$4s^3S_1-4p^3P^o_1$	0-1	32.9						
C III	7485.2	$5d^3D_3-6f^3F^o_4$	2	81.8	5	81.6			8n	91.9
(O V	7483.0	$4s^3S_1-4p^3P^o_2$)								
C II	*7506.8		2	18.4	4	15.9				
C II	7521.6	$5p^2P^o-3p^2D$								
C II	7525.7									
C II	7509.4									
C II	7520.0	$2p^3\,{}^2P^o-3p^2P$								
C II	7520.5									
C II	7531.0									
O III	7514.1	$4s^3P^o_2-4p^3P_1$								
O IV	7510.5	$4p^2D_{1\frac{1}{2}}-4d^2P^o_{\frac{1}{2}}$								
O II	7504.0	$3d\,{}^2G_{4\frac{1}{2}}-5f^2G^o_{4\frac{1}{2}}$								
O III	7550.4	$3s^3P_0-3p^3S^o_1$	1	51.4	1s?	49.7				
C III	*7576.6		3	83.9	7	85.9	5	...	10	?95?
C III	7585.8									
C III	7595.2	$3s^3P^o-4d^3D$								
C III	7611.8									
C III	7625.5									

Table 2 (continued)

Identification			HD 184738 (WC8)		HD 164270 (WC8)		HD 168206 (WC7)		HD 192103 (WC7)	
Element	λ	Designation	Int	λ	Int	λ	Int	λ	Int	λ
C III	7592.8									
C III	7614.0	$3d\,^3F^o-5g\,^3G$								
C III	7613.5									
O III	7606.0	$3s\,^3P_1-3p\,^3S^o{}_1$								
O IV	7588.6	$4p\,^2D_{1\frac{1}{2}}-4d\,^2P^o{}_{1\frac{1}{2}}$								
Si IV	7656.7	$6p\,^2P^o{}_{1\frac{1}{2}}-7s\,^2S_{1/2}$	1-0	62.5						
O IV	7651.9	$3p''\,^2D^o-5p\,^2P$								
O IV	7669.0									
Si IV	7678.3	$6f\,^2F^o{}_{3\frac{1}{2}}-7g\,^2G_{4\frac{1}{2}}$	0	82.3			1	81.9		
C IV	7704.5	$6d\,^2D-7f\,^2F^o{}_o$	3	8.8	5	5.3				
C III	7707.4	$3p\,'P_1-3d\,'D^o{}_2$								
O III	7711.2	$3s\,^3P_2-3p\,^3S^o{}_1$								
C IV	*7704.5	$6d\,^2D-7f\,^2F^o$	2	26.4	5	32.2	6	27.7	20	26.0
C IV	7723.7	$6f\,^2F^o-7g\,^2G$								
CIV	7726.1	$6g\,^2G-7h\,^2H^o$								
C IV	7726.6	$6h\,^2H^o-7g\,^2G$								
C IV	7728.0	$6g\,^2G-7f\,^2F^o$								
C IV	7746.2	$6f\,^2F^o-7d\,^2D$								
(O IV	7715.1	$4p\,^2D_{2\frac{1}{2}}-4d\,^2P^o{}_{1\frac{1}{2}}$)								
(Si IV	7716.8	$6g\,^2G_{4\frac{1}{2}}-7h\,^2H^o{}_{5\frac{1}{2}}$)								
(Si IV	7730.8	$6h\,^2H^o-7g\,^2G$)								

Table 2 (continued)

Identification			HD 184738 (WC8)		HD 164270 (WC8)		HD 168206 (WC7)		HD 192103 (WC7)	
Element	λ	Designation	Int	λ	Int	λ	Int	λ	Int	λ
C III	*7771.1	$3p^3S_1-3d^3P^o_0$	3	73.0					2?	75.2
(Si III	7772.3	$3d^3D^o_2-5g^3G_3$)								
(O I	7772.0	$3^5S^o_2-3^5P_3$)								
C III	*7779.9	$3p^3S_1-3d^3P^o_1$	2	83.8	6	87.6				
C III	*7795.9	$3p^3S_1-3d^3P^o_2$	3	95.7					2?	99.8
(Si III	7803.3	$3d^3D_3-5g^3G_{3,4}$)								
(C II	7853.2	$4f^2F^o_{2\frac{1}{2}}-3p^4D_{1\frac{1}{2}}$)	2	56.9			1?	59.0	4	61.8
O III	7872.5	$4p^3D_2-4d^3D^o_2$	2	81.4	2n	76.7				
O III	7910.5	$4p^3D_2-4d^3D^o_1$	0	13.3						
O IV	7938.1	$3d'^2P^o_{1\frac{1}{2}}-4f^2D_{1\frac{1}{2}}$	0	43.7			1?	37.1	2	46.2
O IV	7944.4	$4p^2D_{2\frac{1}{2}}-8f^2F^o_{2\frac{1}{2},3\frac{1}{2}}$								
C III	7969.3	$5g'G_4-6f'F^o_3$	1?	69.7	1	61.0	1?	63.6		
C IV	7957.7	$6d^2D-7p^2P^o$								
O III	7962.8	$4p^3D_3-4d^3D^o_3$								
C III	8019.5	$5d'D_2-6f'F^o_3$			2-3	19.0				
C II	8061.9				2	68.9				
C II	8062.5	$3p^4P-3d^4P^o$								
C II	8076.5									
(OV	8061.0	$4p^3D_1-4d^3P^o_0$)								
(OV	8068.8	$3d'P^o_1-4s'S_0$)								
C III	8144.5	$5g^3G-6f^3F^o$			Is?	42.0				
C III	8145.1									
C II	8161.4	$3d^2P^o_{1\frac{1}{2}}-4p^2P_{1\frac{1}{2}}$	1?	64.1						

Table 2 (continued)

Identification			HD 184738 (WC8)		HD 164270 (WC8)		HD 168206 (WC7)		HD 192103 (WC7)	
Element	λ	Designation	Int	λ	Int	λ	Int	λ	Int	λ
O III	*8172.2	$4s'P^{o}_{1}-4p'D_{2}$	5	96.1	8	95.3	4	3.8	8	...
O V	8205.2	$4p^{3}D_{2}-4d^{3}P^{o}_{1}$								
C II	8176.8									
C II	8177.5	$3d^{2}P^{o}-4p^{2}P$								
C II	8193.0									
C III	*8255.0	$3d^{3}F^{o}_{2}-5d^{3}D_{3}$	1?	42.1	5	47.4			6	42.1
							2	55.5		
C III	*8272.0	$3d^{3}F^{o}_{3}-5d^{3}D_{3}$	1	60.7	5	66.0			5	62.2
C III	8297.2	$3d^{3}F^{o}_{4}-5d^{3}D_{3}$			2?	97.6				
C III	*8322.4	$3d'P^{o}_{1}-6d'D_{2}$	2	8.8						
C III	8335.1	$3p'S_{o}-6p'P^{o}_{1}$			4	20.0				
C I	*8335.2	$3s'P^{o}_{1}-3p'S_{o}$	3	28.3			4	41.0	8	27.6
C III	8333.6									
C III	*8342.7		4	43.0	10	40.1				
C III	8348.7	$4d^{3}D-3d^{3}F^{o}$								
C III	8359.0									
C III	8360.1									
O V	8311.6	$7d'D_{2}-8p'P^{o}_{1}$								
O III	8339.5	$4p^{5}D^{o}_{2}-4d^{5}P_{1}$								
C II	8330.1 to 8357.1	$3p^{4}P-3d^{2}D^{o}$								
O III	8356.7	$4p'P_{1}-4d'D^{o}_{2}$	1	54.6						
He I	8361.77	$3^{3}S-6^{3}P^{o}$								

Table 2 (continued)

Identification			HD 184738 (WC8)		HD 164270 (WC8)		HD 168206 (WC7)		HD 192103 (WC7)	
Element	λ	Designation	Int	λ	Int	λ	Int	λ	Int	λ
C II	8379.1	$4d^4F^o_{3\frac{1}{2}}-5f^4D_{3\frac{1}{2}}$	1-0	95.6	2?	80.9			2?	87.7
C II	8398.7	$4d^4F^o_{4\frac{1}{2}}-5f^4D_{3\frac{1}{2}}$								
C III	8367.4									
C III	8370.9	$4p^3P^o-3p^3P$								
C III	8393.2									
C III	8396.7									
O II	8376.5	$4p^4D^o-5s^4P$								
O II	8382.8									
O III	8365.1									
O III	8377.1	$4p^3D-3p^3P^o$								
O III	8385.8									
P_{20}	8392.40	$3^2D-20^2F^o$								
C II	8413.9	$3p^4S_{1\frac{1}{2}}-3d^4D^o_{2\frac{1}{2}}$	0?	15.2	2?	5.5				
C II	8413.6	$4d^4F_{4\frac{1}{2}}-5f^4G_{5\frac{1}{2}}$								
C IV	8403.9	$6p^2P^o_{\frac{1}{2},1\frac{1}{2}}-7s^2S_{\frac{1}{2}}$								
O II	8404.5	$4p^4D^o-5s^4P$								
O II	8417.0									
P_{19}	8413.3	$3^2D-19^2F^o$								
O I	*8446.3	$3^3S^o_1-3^3P_2$	1	42.9						
O III	8442.3	$4p^5D^o_3-4d^5P_2$								
P_{18}	8437.96	$3^2D-18^2F^o$								
O III	8461.9	$4p^3D_2-3p^3P^o_2$	0	66.8						
C III	*8499.7	$3s^1S_0-3p^1P^o_1$	3	0.2	8	97.7	3	8.0	8	99.1

Table 2 (continued)

Identification			HD 184738 (WC8)		HD 164270 (WC8)		HD 168206 (WC7)		HD 192103 (WC7)	
Element	λ	Designation	Int	λ	Int	λ	Int	λ	Int	λ
C II	8568.7	$4d^4F^o-5f^2F$	0	72.0						
C II	8579.5									
C II	8590.5	$4d^4F^o_{3\frac{1}{2}}-5f^4F_{4\frac{1}{2}}$								
C II	8594.8	$4d^4F^o_{3\frac{1}{2}}-5f^2F_{2\frac{1}{2},3\frac{1}{2}}$								
P_{14}	8598.4	$3^2D-14^2F^o$								
O III	8581.7	$4p^5D^o_4-4d^5P_3$								
C II	8611.9	$4d^4F^o_{4\frac{1}{2}}-5f^4F_{4\frac{1}{2}}$			2?	11.1				
C II	8615.4	$4d^4F^o_{4\frac{1}{2}}-5f^2F_{3\frac{1}{2}}$								
O III	8612.8	$4p^3D_3-3p^3P^o_2$								
C III	*8665.4	$5f^3F^o-6g^3G$	3	63.4	6	61.2	3	60.6	8	65.9
C III	8666.7									
C III	8667.2									
(C III	8662.0	$5p'P^o_1-6s^3S_1$)								
O IV	8669.9	$4p^2D_{2\frac{1}{2}}-4d^2F^o_{2\frac{1}{2}}$								
C II	8681.3	$4s^2S-2p^3\ ^2P^o$								
C II	8695.4									
O II	8680.0	$4d^4F-5f^4F^o$								
O II	8690.6									
P_{13}	8665.0	$3^2D-13^2F^o$								

NOTES TO TABLE 2

*λ 6562.8—In HD 164270 and HD 168206 the shortward wing is stronger than the longward. In HD 168206 the emission is definitely double.

*λ 6578.0—*C* IV contributes probably to the emission in the WC7 stars but not appreciably to that in the WC8 objects.

*λ 6744.2—In HD 164270 there may be some weak emission between λ 6736 and λ 6785.

*λ 6847.8—The *O* III identification is doubtful, since it is an intersystem combination.

*λ 6857.3, *λ 6881.9—In HD 192103 there may be some absorption between λ 6861 and λ 6895. The complex emission λλ 6861–6895 is also weakly present in HD 168206.

*λ 7065.2—This line has a complex profile in HD 164270, the longward half appearing weaker than the shortward; it may actually be a double line.

*λ 7109.1, *λ 7136.8—On one spectrogram of HD 164270 the emission near λ 7120 appears single at λ 7120.0, with $W = 880$; on the other plate the double character is suspected. In HD 168206 the emission appears single.

*λ 7231.1, *λ 7236.2—This is the strongest infrared line in the WC8 stars. The total half-width is $W = 433$ in HD 184738, $W = 950$ in HD 164270 (with probable weak reversal). In HD 168206 the line is double, with components centered at λ 7219.4 (int. 10, $W = 344$) and λ 7253.7 (int. 9, $W = 468$). In HD 192103 the line is double, with components at λ 7217.9 (int. 12, $W = 465$) and λ 7250.6 (int. 11, $W = 533$).

*λ 7281.3—The double structure in HD 184738 is uncertain; on one plate the emission is measured as single at λ 7281.9.

*λ 7380.2—In HD 164270, the emission is suspected to be double at λλ 7355.3–7379.5. The shortward component may be due to *O* III (λλ 7343.8–7366.1).

*λ 7506.8—In HD 164270 there is some emission between these two lines.

*λ 7576.6—This emission, which is present in all four stars, is sharply and deeply cut by atmospheric absorption; it is hard to estimate the position of the maximum, or even the line intensity or structure. In HD 168206 the emission begins at λ 7576.6. In HD 192103 it extends from λ 7569.4 to λ 7621.4. In HD 184738 a line is measured at λ 7618.2 on the longward side of the atmospheric absorption.

*λ 7704.5—This is a very intense, wide, and shallow emission in HD 192103, the large width being mainly due to the blending of several 7 → 6 transitions in *C* IV. In HD 184738 the λ 7726.4 emission is wider than λ 7708.8, and a triple structure is suspected at λλ 7725.1, 7733.2, and 7744.5.

*λ 7771.1, *λ 7779.9, *λ 7795.9—While the triple structure of this group appears fairly well on one spectrogram of HD 184738, the emission on another plate is found to be a wide line with minimum at λ 7790.1. In HD 164270 no definite structure appears. In HD 192103 there seem to appear at least two components.

*λ 8172.2—This emission is complex in HD 192103. Either it may be described as double, with first component at λ 8179.8 ($W = 431$) and second at λ 8209.7 ($W = 390$); or it may be triple with two fairly sharp components at λλ 8172.6–8187.2 and a broader one at λ 8209.7. By comparison with the *C* II line at λ 8161, the *C* II contribution to this emission should be minor.

*λ 8255.0, *λ 8272.0—In HD 168206 the double structure is not seen; in HD 192103 it is only suspected.

*λ 8322.4, *λ 8335.2, *λ 8342.7—This is a complex emission. It is resolved on one spectrogram of HD 184738. In HD 164270 and HD 192103 the structure is only suspected. On one spectrogram of HD 168206 there seems to be a reversal at λ 8341.0.

*λ 8446.3—This line may belong to the nebula.

*λ 8499.7—This emission has a complex structure in HD 192103. In HD 168206 there is a weak central reversal.

*λ 8665.4—In HD 192103, this emission appears to have three maxima at λλ 8647.0 (int. 8), 8664.1 (int. 7), and 8680.2 (int. 6).

Table 3

Nitrogen Sequence

Identification			HD 151932 (WN6+)		HD 192163 (WN6)		HD 193077 (WN5)	
Element	λ	Designation	Int	λ	Int	λ	Int	λ
Hα	6562.8	$2^2P^o-3^2D$	10	62.9	20	62.2	20	62.3
He II	6560.1	$4^2F^o-6^2G$						
N II	*6610.6	$3p^1D_2-3d^1F^o_3$					1-2	11.5
N III	*6642.6	$4d^2D_{2\frac{1}{2}}-3d^4D^o_{2\frac{1}{2}}$					1	42.7
He I	6678.1	$2^1P^o_1-3^1D_2$	3	80.8	8	76.3	2-3	85.7
N V	*6719	$7^2S-8^2P^o$			2	21.6	1s	16.6
(N I	6645.0	$3p^4D^o_{3\frac{1}{2}}-5s^4P_{2\frac{1}{2}}$)						
N III	*6767.4	$3d^2F^o_{2\frac{1}{2}}-6d^2D_{2\frac{1}{2}}$			1?	69.8		
			4A	74.5			5A	69.4
(N II	*6888.7	$3p^5S^o_2-3d^5P_3$)			3	95.3		
N III	6965.4	$3p'^2D_{2\frac{1}{2}}-4d^2F^o_{2\frac{1}{2}}$			2?	65.4		
He I	*7065.2	$2^3P^o_{2,1}-3^3S_1$	2	71.6	2	57.0	1	53.5
(Si IV	7046.1	$5d^2D_{2\frac{1}{2}}-6p^2P^o_{1\frac{1}{2}}$)						
N IV	*7109.2	$3p^3P^o_1-3d^3D_2$	4	5.0				
					25	11.4	20	14.4
N IV	*7123.1	$3p^3P^o_2-3d^3D_3$	4	22.3				
N II	*7139.8	$3d^3P^o_2-4p^3D_3$	1?	47.8			2?	43.0
(He II	7177.5	$5^2G-11^2H^o$)			3?	69.9		
			0?	83.9			1?	72.0
N II	7217.0	$3d^3P^o_1-4p^3D_2$	2	16.4			2	20.6
N II	7259.3	$3d^3P^o_0-4p^3D_1$			2s?	53.0		
He I	7281.3	$2^1P^o_1-3^1S_0$			2s?	79.6		
N V	*7320.8	$7^2P^o-8^2D$	2	33.8				

Table 3 (continued)

Identification			HD 151932 (WN6+)		HD 192163 (WN6)		HD 193077 (WN5)	
Element	λ	Designation	Int	λ	Int	λ	Int	λ
N III	7355.5	$3p^2D_{1\frac{1}{2}}-3d^2D^o_{2\frac{1}{2}}$			0	50.2		
Si III	7355.0	$4d^3D_{3,2,1}-3d^3P^o_2$						
N III	*7410.8	$3s^4P^o_{1\frac{1}{2}}-4s^2S_{\frac{1}{2}}$			1	10.3		
N III	7403.7	$3p^2D-3d^2D^o$						
N III	7418.3							
N II	7444.0	$3d'F^o_3-4p^3D_2$	1s?	38.6				
N II	7510.1	$3d^3P^o_2-4p'P_1$	1s?	5.3				
N V	*7600.2	$7d^2D-8f^2F^o$	3	...	15	?90.9	10	?90.1
N V	7615.8	$7f^2F^o-8g^2G$						
N II	7609.1	$3d'P^o_1-4p^3P_2$						
He II	7592.7	$5^2G-10^2H^o$						
N III	7685.6	$5d^2D_{2\frac{1}{2}}-6f^2F^o_{3\frac{1}{2}}$			3?	86.9		
Si IV	7678.3	$6f^2F^o_{3\frac{1}{2}}-7g^2G_{4\frac{1}{2}}$						
N III	7859.9	$3d^4F^o_{4\frac{1}{2}}-5g^2G_{3\frac{1}{2},4\frac{1}{2}}$					2	68.3
N II	7897.9	$4p'P_1-5s'P^o_1$			1s?	7.8	0	91.5
N II	7906.3	$3d'P^o_1-4p^3D_2$						
N III	*8022.2	$5f^2F^o_{3\frac{1}{2}}-6g^2G_{3\frac{1}{2},4\frac{1}{2}}$			4	5.3		
N III	*7970.1	$4d^2D-3d^4F^o$			3	35.0		
N III	7983.3							
N III	8003.1							
N III	8005.7							
N III	8025.7							
N III	7967.1	$3s^2P^o-3p^4D$						
N III	7989.7							
N III	7999.5							
N III	8039.5							

Table 3 (continued)

Identification			HD 151932 (WN6+)		HD 192163 (WN6)		HD 193077 (WN5)	
Element	λ	Designation	Int	λ	Int	λ	Int	λ
N III	8062.5	$3s^2P^o_{1\frac{1}{2}}-3p^4D_{\frac{1}{2}}$	2?	55.7				
N II	8089.1	$3p'D-3d^3F^o$	2n?	7.6				
N II	8128.2							
....	*......	....			6	13.2	4	12.1
....	*......	....	8	29.5	7	42.7	6	44.6
(N II	*8253.3	$4p^3D_1-5s'P^o_1$)			4-5	?59.4	1?	55.8
(N II	8288.1	$4p^3D_2-5s'P^o_1$)						
(N II	8297.4	$3d'P^o_1-4p'P_1$)						
N III	8306.4	$3s^2P^o_{\frac{1}{2}}-3p^2P_{1\frac{1}{2}}$			1s?	12.2	1?	27.8
He I	*8361.8	$3^3S-6^3P^o$					2	59.4
N II	8589.3	$4p^3P_1-5s'P^o_1$	2	88.9				
(N I	8594.0	$3s^2P_{\frac{1}{2}}-3p^2P^o_{\frac{1}{2}}$)						
N II	8660.7	$4p^3D-5s^3P^o$	2	99.9				
N II	8675.7							
N II	8695.2							
N II	8699.1							
N II	8698.4	$4d^3F^o-5f^3G$						
N II	8702.2							
N II	8710.8							
N II	8703.3	$4d^3F^o_4-5f'G_4$						
N II	8686.9	$2p^3{}'P^o_1-3p'S_o$						
(N I	8680.2 to 8747.3	$3s^4P-3p^4D^o$)						
N III	8738.3	$4p^2P_{1\frac{1}{2}}-4d^4P^o_{2\frac{1}{2}}$	0	40.7				
(P$_{12}$	8750.5	$3^2D-12^2F^o$)						

NOTES TO TABLE 3

*λ 6610.6, *λ 6642.6—These two lines are difficult to measure and somewhat uncertain. Other transitions of the $4d^2D-3d^4D°$ multiplet may contribute to the emission at λ 6642.7; these other transitions are λλ 6644.5, 6638.6, 6628.9, 6652.3, and 6630.1.

*λ 6719, *λ 6767.4—Measurement difficult in HD 192163.

*λ 6874.5—This looks like an absorption feature; however, it may simply be a narrow spacing between two unidentified emissions.

*4 6888.7—This emission is also weakly present in HD 151932 and HD 193077.

*λ 7065.2—Difficult to measure in shortward wing of the intense *N* IV emission.

*λ 7109.2, *λ 7123.1—Other weaker components of the *N* IV multiplet contribute to this emission. In HD 192163 the width is hard to determine, since weak additional emissions appear in the wings which extend farther than in HD 193077.

*λ 7139.8—Difficult to measure on longward side of the intense *N* IV emission.

*λ 7320.8, *λ 7410.8—Measurement difficult and uncertain.

*λ 7600.2—This is a strong emission which is sharply and deeply cut by atmospheric absorption. It is not possible to determine the line centers and widths with accuracy. Four $8 \rightarrow 7$ transitions of *N* V fall near λ 7600.

*λ 8022.2, *λ 7970.1—This may be a single emission with reversal at λ 8021.5.

*λ 8213.2, *λ 8242.7, *λ 8259.4—Complex pattern. The triple structure is well marked on two of the three spectrograms of HD 192163 (see Fig. 2). In HD 151932 a broad emission with sharp reversal at 8229.5 is observed; the line extends from λ 8198.6 to λ 8255.4. In HD 192163 there may be a reversal at λ 8228.6, between the components of intensities 6 and 7. In HD 193077 the minimum (reversal?) is measured at λ 8228.6.

*λ 8361.8—There may be a minor contribution by the $3p^2D-4d^4D°$ multiplet of *N* III, extending from λ 8344.3 to λ 8387.0.

tions. As appears readily from an examination of the *Revised Multiplet Table*, little laboratory work has been done on the infrared spectra of the ions which are of interest for Wolf-Rayet stars (*C* II–IV, *N* II–V, *O* II–VI, *Si* III and IV). On the basis of the term table recently published by C. E. Moore,[4] all the permitted transitions between known terms were computed for the wave-length region λλ 6500–8800. For *C* II, the intersystem combinations are weak, yet have been considered; for *C* III no intercombination has been computed. In *N* II, the singlet and triplet terms are well connected by intersystem combinations; intercombinations have also been considered for *N* III, but not for *N* IV; for *N* V, the predicted wave lengths are rather poor, since they are based on extrapolations in term-series formulae. Since the oxygen ions should give only fairly weak lines, the intersystem combinations have been mostly omitted for *O* II–VI. The same applies to *Si* III.

It is obvious that such tables of predicted lines do not permit as safe and complete identifications as would tables of laboratory lines. Only little help may be found in the relative intensities; moreover, certain predicted transitions may actually be too weak to appear in the laboratory, while new lines may be found experimentally, leading, actually, to new terms. Unsatisfactory as the procedure is, there did not seem to be any alternative, pending a laboratory investigation of the infrared region of the spectra of the ions concerned. Indeed, it is hoped that the publication of the present results will serve as an incentive to laboratory spectroscopists.

Our results are collected in Tables 2 and 3. For each star, we give the estimated intensities and the mean wave lengths of the line centers. Doubtful identifications or minor contributions are in parentheses. Asterisks preceding entries in the first column of wave lengths refer to notes concerning the stellar lines. Most strong lines of the WC stars are satisfactorily identified. The line at λ 7862 is not well identified, while the patterns near λ 8330 and λ 8250 are not convincingly disentangled. The situation is worse in the case of the WN stars. The double emission at λ 8005 and λ 8035 is not too well explained. Worse still is the case of the complex emission near λ 8240. In this pattern the two strongest components near λ 8213 and λ 8244 are unexplained. An important contribution by the $3s^4P-3p^4P^\circ$ multiplet of *N* I, extending from λ 8188 to λ 8242, appears unlikely; *He* II can play only a minor role. From a comparison between the three stars it seems that the pattern is due to at least two ions. It is rather tempting to assume that λ 8213 and λ 8244 are due to *N* III. The half-widths of the lines in kilometers per second (ejection velocities) are listed separately in Tables 4 and 5.

Figures 1 and 2 show that a strong emission appears in both sequences around the intense telluric absorption near λ 7600. This emission starts on the shortward side of the atmospheric absorption. In the WC sequence, the emission is fairly well explained by the $3s^3P^\circ-4d^3D$ multiplet of *C* III, while in the WN sequence the identification with *N* V + *N* II does not seem so convincing. The profiles of the emissions appear so similar in the WC and WN sequences (although not quite identical) that one would feel tempted to attribute these emissions to the same atom. Pending more definitive identifications no attempt will be made here to discuss either the widths of the lines or the possibility of coexistence of carbon and nitrogen lines.

Our thanks are due to Mrs. D. Crespin Sengier for her help in preparing the tables of predicted lines.

[4] *Atomic Energy Levels* (Circ. Nat. Bur. Stand. No. 467), 1949.

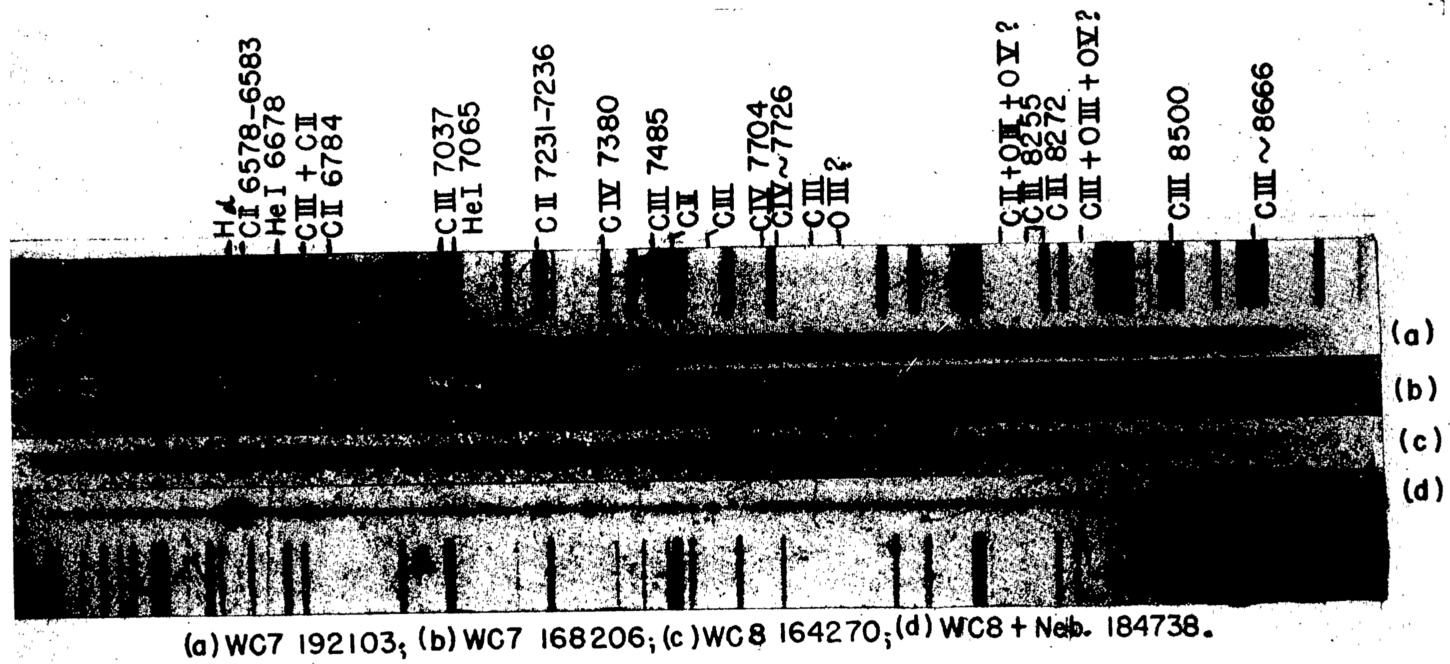

FIG. 1.—Infrared spectra of WC stars

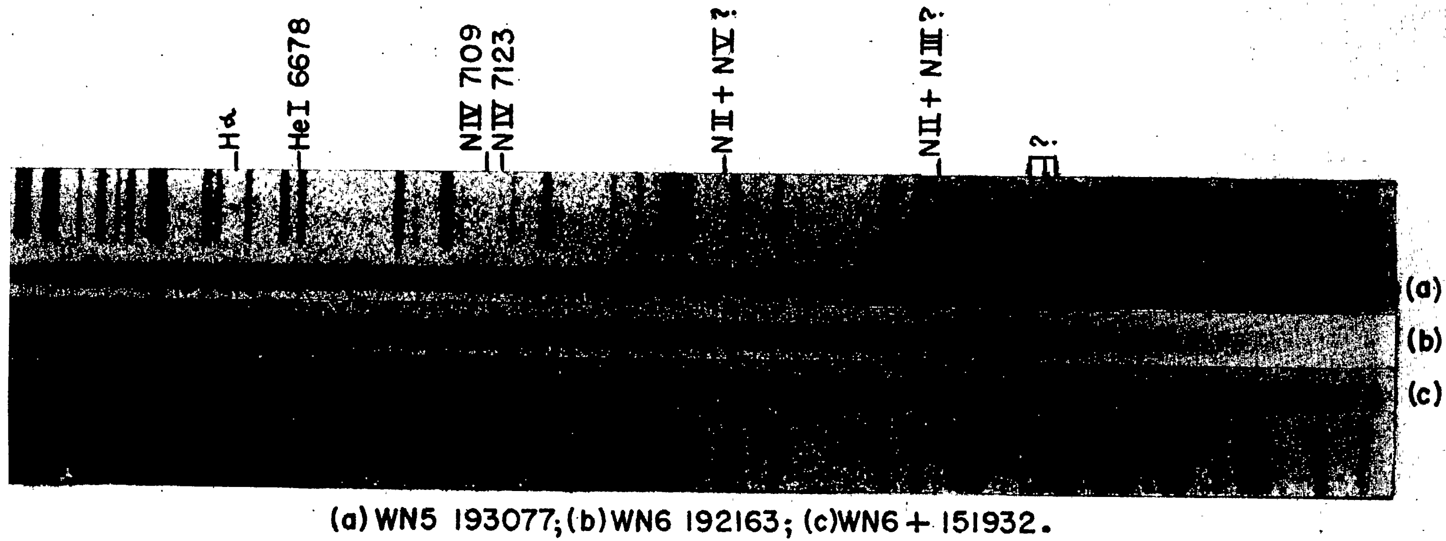

FIG. 2.—Infrared spectra of WN stars

TABLE 4

LINE WIDTHS (CARBON SEQUENCE)

HD 184738 (WC8)		HD 164270 (WC8)		HD 168206 (WC7)		HD 192103 (WC7)	
λ	W	λ	W	λ	W	λ	W
						6565.4	557
		6581.8	780	6577.9	1070		
		6680.2	730			6596.4	537
6730.1	738	6736.5	815	6747.3	1077	6740.8	600
6780.7	526	6785.0	555			6894.6	683
7035.6	309	7033.1	328	7053.5	1165	7025.6	897
7064.4	332	7062.3	785			7060.2	595
				7126.9	924		
		7231.5	950			7378.9	520
				7681.9	730		
		7705.3	385				
		7732.2	428	7727.7	842	7726.0	935
		7787.6	830				
						7861.8	744
		8068.9	586				
		8195.3	605	8203.8	740		
				8255.5	675		
		8320.0	791	8341.0	726	8327.6	995
		8497.7	330	8508.0	797	8499.1	875
						8665.9	750

TABLE 5

LINE WIDTHS (NITROGEN SEQUENCE)

HD 151932 (WN6+)		HD 192163 (WN6)		HD 193077 (WN5)	
λ	W	λ	W	λ	W
6562.9	590	6562.2	1283	6562.3	754
6680.8	840	6676.3	1215		
		6721.6	1005?		
		6895.3	886		
		6965.4	1017		
		7057.0	1020		
		7111.4	1323	7114.4	599
		7169.9	945		
		7590.9	1105	7590.1	993
		8213.2	347	8212.1	248
8229.5	1030	8242.7	371	8244.6	378
		8259.4	348		