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COUDÉ SPECTRA OF ETA CARINAE AND THE STRONGEST LINES OF [Fe II] AND [Ni II]

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Summary

Coudé spectra of the nucleus of η Carinae in the ranges of wavelength 3100–4250 Å and Hβ–6850 Å have been measured. Wavelengths and estimated intensities are listed in Table IIa and b.

Garstang's transition probabilities for [Fe II] and [Ni II] have been invaluable in assigning new identifications, the agreement with observed intensities being very good. Over 100 [Fe II] lines belonging to 33 multiplets and 19 [Ni II] lines belonging to 7 multiplets are indentified. The [Fe II] intensities together with Garstang's data suggest an excitation temperature of order 8500 ± 1500 °K.

An interesting new identification in the ultra-violet is [N I] 3466. The [Ne III] lines disappeared temporarily in 1965, and the He I emission was simultaneously weakened. [S II] 6717, 6730 seem to have strengthened. Displaced absorptions are prominent in the Balmer lines and for other lines especially Ti II. Such structures vary with time.

1. *Introduction.* The spectrum of η Carinae was studied by the writer with the two-prism Cassegrain spectrograph attached to the Radcliffe reflector as soon as this equipment became available in 1951. Numerous emission lines were identified between 3700 and 8900 A (Thackeray 1953—in future 'paper I'), but the dispersion was low in the red and infrared regions, and beyond 3800 Å absorption in prisms and lenses rendered the spectra weak.

The installation of the Radcliffe coudé spectrograph with grating-mirror optics opened up both the ultra-violet and infra-red regions. The infra-red region was first studied (Thackeray 1962—in future 'paper II') on account of the strong unidentified lines already noted on low dispersion (see Plate 1). Plates in the visual and ultraviolet regions were also secured. Measurement and reduction of this latter material has been unfortunately delayed owing to other commitments. The present paper lists lines measured in the region 3076–4244 Å (Table Ia) and Hβ–6900 Å (Table Ib). The intermediate region, 4244–Hβ, seems to have been for the most part adequately covered by the cassegrain spectrograph although some known blends are resolved at coudé dispersion.

In the meantime Garstang (1957, 1958, 1962) has published some extremely valuable transition probabilities for forbidden lines of Fe II, Ni II etc. These transition probabilities agree very well with published visual estimates by the writer of [Fe II] and [Ni II] intensities. Further, they have served as an excellent guide to identifying certain lines, not listed in *Revised Multiplet Table*. A few such transitions in η Carinae had already been suggested by the writer in Paper I. These are confirmed and extended by Garstang's work.

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2. *Observations and measurements.* Table I lists six available coudé spectra of which all but one have been measured with results that are reported in this paper.

TABLE I

Plate	Date	Exposure (min)	Grating order	Emulsion filter	Measurer
DZ 31	1960 May 18	8	I	103aF + Aero 1	ADT, SRH
DZ 43	1960 June 8	31	I	103aF + Wrat 8	ADT
DZ 52	1960 June 9	20	II	IIaO	
DY 646	1961 May 18	60	II	103aO	SRH
DZ 658	1961 May 20	50	II	IIaO	SRH
DZ 1310	1965 March 19	80	II	IIaO (baked)	IM

DZ plates were taken with the 21 in. camera giving dispersions of 15·6 and 31·2 Å/mm in II and I orders respectively. The DY plate was taken with the 48 in. camera giving a dispersion of 6·8 Å/mm in II order.

All the plates were taken by the writer. The nucleus of the nebulous object was always held on the slit, and usually trailed along the slit, but on DZ 1310 it was held fairly centrally on the slit without much trailing.

In the measurement and reduction of the rich spectra the writer has had the invaluable assistance of Mrs S. R. Hill and Mrs I. Malin whose initials appear in the last column opposite the relevant plates. The plates were measured on Hilger long-screw micrometers, direct and reverse, in the usual way. For the last three spectra the writer selected all visible lines for measurement and assigned visual estimates of intensity at the same time; a very small number of the faintest features were subsequently rejected. These intensities (or combinations from duplicate plates) appear in Tables IIa and b, together with mean measured wavelengths and identifications. In addition, the writer measured all absorptions visible on plate DZ 658 beyond K, and these measures are included in Table IIa.

3. *Description of Tables IIa and b.* The results are presented in the same general form as in papers I, II. The mean measured wavelength was derived after correction for the Earth's orbital velocity and for a stellar velocity of −25·1 km/s with respect to the Sun, and should thus be directly comparable with laboratory wavelengths, except for displaced absorptions.

In the second column the following notations are used:

A, absorption (otherwise emission is always understood).

n, N, NN, indicate increasing degrees of diffuseness.

w, W, marked wings (probably arising largely in the surrounding halo).
d, double.

s, sharp.

?, doubt as to reality of feature.

r, v, a weak blend to red or violet of main line.

TABLE IIa

Spectrum of Eta Carinae 3100–4250 Å

* Lines double at 6·8 Å/mm;
† Lines markedly weakened in 1965

λm	Int.	n	Identification							
3076·3	1	1	Ni II	6F	76·1					
3118·9	?1N	2	Ca II	5	18·65	(60)				
25·3:	?1N	2	Cr II	5	24·98	(100)				
28·0	?15A	1	Cr II	5	32·06	(125)				
32·4	2N	2	Cr II	5	32·06	(125)				
35·4	1N	1	Fe II	82	35·36	(9)				
36·9	1N	1	Cr II	5	36·68	(40)				
47·36:	?2n?d	1	Cr II	5	47·23	(50),	Fe II	67	46·75	(2)
54·18	3	2	Fe II	66	54·20	(12)				
55·9	1n	2	Fe II	67	55·95	(2)				
62·00	2·5	2	Fe II	7	61·95	(5)				
63·06	2·5	2	Fe II	7	63·09	(5),	Fe II	120	62·80	(8)
66·56:	?1	2	Fe II	6	66·67	(4)				
67·79	2·5	2	Fe II	66	67·85	(11)				
70·3	2	1	Fe II	6	70·34	(6)				
75·5	0·5	1	Fe II	11F	75·38					
77·56	3	2	Fe II	82	77·53	(10)				
81·08	2N?d	2	Cr II	9	80·73	(75),	?Fe II	12F	81·05	
83·18	3	2	Fe II	7	83·12	(8)				
85·32	4	2	Fe II	7	85·32	(5)				
87·08	4N	2	Fe II	6	86·74	(11),	Fe II	120	87·29	(8)
92·96	3	2	Fe II	6	92·92	(9)				
93·93	4N	3	Fe II	6	93·81	(11),	Fe II	67	93·85	
96·08	4	3	Fe II	7	96·07	(10)				
3197·21	2	1	Cr II	9	97·12	(75)				
3206·0	?200AN	1	?Fe II	6	10·45	(10)				
10·66*	7N	2	Fe II	6	10·45	(10),	Fe II	95	11·07	(1)
12·0	6AN	2								
3213·51*	8N	2	Fe II	6	13·31	(13)				

TABLE IIa (*continued*)

λm	Int.	n	Identification							
3217·46	1·5	2	Cr II	9	17·44	(50)				
22·0	?100AN	1	?Fe II	6	27·73	(13)				
23·18	2·5	2	Ni II	6F	23·16					
23·9	8AN	1	?Ti II	2	29·19	(40)				
27·96*	9N	2	Fe II	6	27·73	(13)				
28·98	1·5	1					?Ti II	36	29·40	(35)
29·48	4A	2	Ti II	2	34·52	(75)				
30·40	5NN	1	?Fe II	95	30·50	(1),	?Fe II	12F	30·17	
31·5	3A	1	Ti II	2	36·57	(70)				
32·45	2N	1	Fe II	119	32·79	(7),	?Ti II	36	32·28	
34·13	10A	1	Ti II	2	39·04	(60)				
34·98	2	1	Fe II	1	34·92	(0)				
37·0	3A	1	Ti II	2	41·98	(60)				
37·61	2N	1	Fe II	81	37·81	(8),	37·40	(5)		
43·74	1	2	Fe II	119	43·72	(8)				
47·36	1·5	2	Fe II	81	47·17	(9)				
53·02	1N	2	?Ti II	2	52·91	(40)				
55·89*	8	2	Fe II	1	55·88	(8)				
58·97	4N	2	Fe II	81	59·05	(10),	58·77	(10)		
60·51	1·5n	1								
64·68	3	2	Fe II	1	64·76	(P)				
66·92	1	1	Fe II	65	66·94	(4)				
71·75	1	1	?Ti II	66	71·65	(25)				
72·92	10AN	1	Fe II	1	77·35	(9)				
77·31	12	3	Fe II	1	77·35	(9),	Fe II	65	77·85	(0)
81·26	10	3	Fe II	1	81·29	(7)				
85·36	2	2	Fe II	1	85·42	(3)				
89·40	2	2	Fe II	65	89·35	(7),	Fe II	11F	89·46	
91·80	?1	1								
95·76	9	3	Fe II	1	95·81	(6),	Cr II	51	95·43	(50)
3297·80	1n	2	Fe II	91	97·89	(5)				
3303·15	8N	3	Fe II	1	02·86	(4),	03·47	(4)		
07·03	2·5	2	Cr II	51	07·04	(50)				
		2	Cr II	51	11·93	(40),	Fe II	1	12·71	(1)

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TABLE IIa (*continued*)

λ m	Int.	n	Identification							
3313·87	3	2	Fe II	1	14·0	(1)				
15·52	1	1	Cr II	51	15·29	(12)				
17·03	0·5	1								
26·86	?1	2								
28·43	1·5	2	Cr II	4	28·35	(20)				
42·79	4N	2	Cr II	4	42·51	(50),	?Ne III	2F	42·9	
44·10	8A	2	Ti II	1	49·40	(125)				
47·82	3	2	Cr II	4	47·84	(40)				
48·76	?4A	2								
49·72	1n	1	Ti II	1	49·40	(125)				
50·36	?2	1	Ni II	1	50·42	(5)				
53·03	1·5	2	Cr II	4	53·12	(20)				
55·35	?1	2								
56·1	8A	2	Ti II	1	62·21	(125)				
58·48	4n	2	Cr II	4	58·50	(70),	Fe II	77	58·25	(3)
							Fe II	5	58·78	
60·19*	3	2	Cr II	21	60·29	(100),	Fe II	105	60·10	(3)
61·66	3n	2	Cr II	21	61·77	(30),	Ti II	1	61·21	(125)
67·62	4A	2	Ti II	1	72·80	(100)				
68·32*	1·5	1	Cr II	4	68·05	(150)				
73·9†	3n	1	Ni II	1	73·98	(4)				
75·07	5AN	2	Ti II	1	80·28	(30)				
76·11	7	2	Fe II	26F	76·20					
78·08	3	2	Ni II	5F	78·20,		?Cr II	21	78·34	(25)
78·7	6A	1	Ti II	1	83·76	(125)				
81·43	1n	2	Fe II	5	81·36	(P)				
88·41	3N	1								
89·3	6A	1	Ti II	1	94·57	(40)				
90·6	6A	1	Cr II	21	93·0, 93·9,	94·3				
91·50	1·5	2	Cr II	3	91·43	(35)				
94·13	1n	1	?Cr II	21	93·86	(30),			94·32	(35)
3398·12	1n	2	Fe II	105	98·35	(4),	?Ni II	8	97·82	(1)
3403·40	2	2	Cr II	3	03·32	(100)				
07·23*	2·5	2	Ni II	4	07·30	(8)				
3408·94	3	3	Cr II	3	08·76	(3)				

TABLE IIa (*continued*)

λm	Int.	n	Identification							
3415·93	6	3	Fe II	16	16·02	(5)				
21·34	2·5	3	Cr II	3	21·20	(75)				
23·03	5n	3	Cr II	3	22·74	(125)				
25·51	?1	1	Fe II	5	25·58	(3)				
33·44*	3n	2	Cr II	3	33·30	(75)				
36·02	2	3	Fe II	91	36·11	(5)				
38·86	6	2	Ni II	5F	38·92					
40·76	3	2	Fe II	26F	40·99					
42·09	5	3	Mn II	3	41·98	(100)				
43·80	1·5	2	Fe II	16	43·83	(P)				
49·26	1n	1								
52·28	3	3	Fe II	26F	52·30					
54·02	2·5	2	Ni II	1	54·16	(5)				
55·03	3	3	Fe II	26F	55·11,		Cr II	136	54·98	(35)
56·89†	2	3	Fe II	76	56·93					
	0·5									
60·47	5	3	Mn II	3	60·31	(75),	Cr II	136	59·29	(25)
62·77	0·5	2	Cr II	2	62·73	(6)				
63·94	1·5	2	Fe II	4	63·97	(1)				
65·48	2	2	Ni II	4	65·62	(1)				
66·33	3	3	N I	2F	66·38,		?Mn II	12	66·34	(9)
68·61	3	2	Fe II	114	68·68	(8)				
71·16	2n	2	Ni II	4	71·35	(2)				
74·17	3	3	Mn II	3	74·04	(50),			74·12	(40)
75·70*	4n	2	Fe II	4	75·74	(P)				
79·86	1·5	2	Fe II	4	79·91	(2)				
82·94	3	2	Mn II	3	82·91	(40)				
84·14	1·5	2	Cr II	2	84·15	(20),	Fe II	27F	84·01	
87·70	1	2	Fe II	4	87·99	(3)				
88·81	2	2	Mn II	3	88·68	(40)				
90·03	1·5	2	Fe II	26F	89·98					
93·44	2	2	Fe II	114	93·47	(10)				
94·57*	4	2	Fe II	16	94·67	(5),	Cr II	2	94·52	(4)
		-	Mn II	3	95·83	(40),	Fe II	115	95·62	(4)

TABLE IIa (*continued*)

λm	Int.	n	Identification							
3496·72	0·5	2	Mn II	3	96·81	(20)				
97·73:	3	2	Mn II	3	97·54	(25)				
3499·74	1n	2	Fe II	115	99·88	(4)				
3501·59	4	3	Fe II	26F	01·62					
03·99	5N	2	Fe II	26F	04·02		Fe II	4	03·47	(2)
04·91	?1	1	Ti II	88	04·89	(80)				
07·35	2	2	Fe II	16	07·39	(3)				
08·27	2	2	Fe II	4	08·21	(1)				
09·55	8A	3	Ni II	1	13·93	(8)				
10·73	1	2	Ti II	88	10·84	(70)				
11·78	2	3	Cr II	2	11·84	(35)				
14·00*	4	2	Ni II	1	13·93	(8)				
32·9	?1n	1	?Fe II	F	32·8	(a^4D-b^2D)				
35·24:*	1·5N	1	?Ti II	98	35·41	(40)				
36·86	2n	1	He I	35	36·82	(1)				
38·95*	4	2	Fe II	26F	38·69, 39·19					
55·89	2	1								
59·33*	4	2	Ni II	5F	59·45					
61·06	1	2								
71·50	?1	1								
75·76	4A	1	?Sc II	3	80·93					
76·67*	4	2	Ni II	4	76·76	(3)				
85·41	5	3	Cr II	13	85·31	(60),			85·54	(40)
3587·23	2n	1	He I	31	87·25	(2)				
3600·0:	0·5	1	?He I	30	99·30	(1)				
03·64	2	2	Cr II	13	03·80	(40),			03·61, 03·86	(20)
08·70	1·5	2	Ni II	4	08·7	(P)				
09·6	?4A	1	?Sc II	2	13·84					
12·90	?2	1	Cr II	13	13·26	(15)				
14·91	1	1	Fe II	112	14·87	(5)				
21·07	3	3	Fe II	144	21·27	(6)				
26·88	5	3	Ni II	5F	26·93					
31·54	3	3	Cr II	12	31·49	(50),			31·72	(40)
34·00	1·5	1	He I	28	34·23	(2)				
3637·23	1	1					?Fe II	112	36·90	(P)

TABLE IIa (*continued*)

λm	Int.	*n*	Identification									
3644·67	?1·5n	1	Cr II	1	44·70	(10)						
47·18	1n	1	Cr II	1	47·40	(8)						
50·52	1	1	?Cr II	156	50·37	(40)						
59·12	1A	1	?H 30		62·26							
60·46	1·5A	1	?H 29		63·41							
61·24	1·5n	1	?H 31		61·22							
61·71	2A	1	H 28		64·68							
62·96	2A	1	H 27		66·10							
64·20	1A	1	H 26		67·68							
65·46	?1A	1	H 25		69·47							
66·02	1s	2	H 27		66·10							
66·98	4A	1	H 24		71·48							
69·4	1A	1	H 23		73·76							
72·47	5A	1	H 22		76·36							
75·0	10AN	1	H 21		79·35							
76·20	2N	1	H 22		76·36							
77·67	6	3	Cr II	12	77·86	(50),			77·69	(40),	77·93	(30)
79·1	6AN	1	H 20		82·81							
80·34†	?2n	1										
82·1	8AN	1	H 19		86·83							
84·27†	2	1	?Cr II	145	84·25	(25)						
85·20	4	2	Ti II	14	85·19	(250)						
87·0	15AN	1	H 18		91·56							
91·0	5n	2	H 18		91·56							
92·77	15AN	1	H 17		97·15							
96·7	8N	2	H 17		97·15							
3699·7	18AN	1	H 16		03·85							
3703·8	10n	2	H 16		03·85							
04·8	10n	2	He I	25	05·00,	(3),		H 16	03·85			
07·65	15AN	1	H 15		11·97							
12·94	5n	2	H 15		11·97,		Cr II	12	12·97	(35)		
									13·04	(15)		
15·24	6n	2	Cr II	20	15·19	(20),	V II	15	15·48			
17·70	20AN	1	H 14		21·94							
3721·10	15N	1	H 14		21·94							

TABLE IIa (*continued*)

λm	Int.	n	Identification							
3726·75	3N	1	V II	21	27·35	(1000)				
29·7	18AN	1	?He I	24	32·9					
30·9	12AN	1	H 13		34·37					
32·7 :	4n	2	He I	24	32·9,		V II	15	32·76	(800)
34·06	5n	2	H 13		34·37					
36·11	5n	1								
38·37†	2 ?1n	2	Cr II	20	38·38	(20)				
41·4	5n	2	Fe II	15	41·56	(P)				
45·63	18AN	1	H 12		50·15					
48·47	5n	3	H 12		50·15,		Fe II	154	48·49	(8)
50·65	4n	3	H 12		50·15,		V II	21	50·88	(600)
52·68	1n	2								
53·77	5AN	1	Ti II	13	59·29	(200)				
54·57†	2·5 1n	2	Cr II	20	54·59	(20)				
55·65	4AN	1	Ti II	13	61·52	(200)				
57·4:	2n	2								
59·62	4n	2	Ti II	13	59·29	(200),	Fe II	154	59·46	(6)
61·63	3	3	Ti II	13	61·32	(200)				
62·72	?2	1								
64·06	5N	3					Fe II	29	64·09	(P)
66·0	12AN	1	H 11		70·63					
67·49	1	1								
69·48	10N	2	Ni II	4	69·45	(5),	H 11		70·63	
71·2	7N	2	H 11		70·63,		V II	21	70·97	(400)
73·4	5N	1	H 11		70·63					
75·64	1	2								
78·12:	1	1								
79·57	1·5	2	Fe II	23	79·58	(P)				
83·23*	6	2	Fe II	14	83·35	(4)				
93·35	15AN	1	H 10		97·90					
3794·17	?1·5	1								

TABLE IIa (*continued*)

λm	Int.	n	Identification							
3798·40	7	2	H 10		97·90					
3800·14	6	1	H 10		97·90					
06·27	4n	3	Cu II	2F	06·34					
15·9	?3A	1	He I	22	19·61	(4)				
19·44†	4n	1	He I	22	19·61	(4)				
21·71:	1n	1	Fe II	14	21·92	(P)				
24·84*	7	2	Fe II	29	24·91	(4)				
30·72	15AN	1	H 9		35·39					
35·73	25N	2	H 9		35·39					
38·24	25N	1	H 9		35·39,		?Mg I	3	38·29	(100)
46·84	1n	1								
49·56	2n	2	Ni II	11	49·58	(2)				
54·45	?0·5	1								
55·89	1·5	2	?Si II	1	56·02	(8)				
68·63†	10	2	Ne III	1F	68·74,		He I	20	67·48	(2)
72·68	1·5	2	Fe II	29	72·76	(P)				
81·34†	?2	2	?Ni II	13	81·92	(1)				
	0·5									
83·4	20AN	1	H 8		89·05,		He I	2	88·65	
88·03	30N	3	He I	2	88·65	(10)				
88·9:	A	2	?He I	2	88·65	(10)				
3889·65	30N	2	H 8		89·05					
3900·57	3	3	Ti II	34	00·55	(70)				
03·06	1	2	V II	11	03·27	(250)				
05·66	2?d	2	Fe II	8F	05·62,		Fe II	173	06·04	(5)
12·29	1·5	1								
14·47	3	3	Fe II	3	14·48					
16·14	1·5	1	?V II	10	16·42	(200)				
28·0:	12A	2	Ca II	1	33·68					
30·23	4	3	Fe II	3	30·31	(P)				
31·81	1	1								
34·01	6As	2	Ca II	1	33·68					
34·59	3	1								
3935·72	4	1	Fe II	173	35·94	(6)				

TABLE IIa (*continued*)

λm	Int.	n	Identification							
3938·23*	7	2	Fe II	3	38·29	(2)				
45·12	5	3	Fe II	3	45·21	(P)				
51·70	1s	2	?V II	10	51·97	(500)				
57·2	?1n	1								
62·48	8A	2	Ca II	1	68·47					
63·70	10A	2	Ca II	1	68·47					
67·30†	7	1	Ne III	1F	67·51					
68·95	4A	2	Ca II	1	68·47					
69·30	8s	3	Fe II	3	69·40	(P),			69·38	(P)
70·24	30N	2	H 7		70·07					
74·09	3n	1	Fe II	29	74·16	(3)				
79·4:	?1	2	?Fe II	9F	79·78,		?Cr II	183	79·51	(20)
81·7:	1N	2	Fe II	3	81·61	(P)				
89·4	?1	1								
3993·03	8	3	Ni II	4F	93·15					
4001·99:	3	2	Fe II	29	02·07	(2)				
05·37	1·5	2	V II	32	05·71	(800)				
11·9:	2	2								
16·04	?1	1					?Ni II	12	15·50	
21·25	10AN	1	He I	18	26·19	(5)				
23·09	0·5	1	V II	32	23·39	(600)				
24·64	2	3	Fe II	127	24·55	(5)				
26·08†	6	2	He I	18	26·19	(5)				
28·15	2	2	Ti II	87	28·33	(7)				
32·84	2	2	Ni II	4F	33·06					
35·37	0·5	2	V II	32	35·63	(400),	Fe II	22	35·54	(P)
44·84	?0·5	1								
53·75	1·5	2	Ti II	87	53·81	(3)				
66·95	4	2	Ni II	11	67·05	(3)				
68·56*	10	2	S II	2F	68·60					
4070·83	1	2	Ni II	11	71·0	(P)				

TABLE IIa (*continued*)

λm	Int.	n	Identification							
4076·34	4	2	S II	2F	76·35					
96·51	8AN	1	H 6		01·74					
4097·40	2	2	N III	1	97·31					
4102·36*	60N	2	H 6		01·74,		N III	1	03·37	
10·56	2	1					Cr II	18	11·01	
14·36*	6	2	Fe II	23F	14·48					
20·62†	1n	1	He I	16	20·81	(3)				
22·53	5	3	Fe II	28	22·64	(4)				
24·58	1·5	2	Fe II	22	24·79	(1)				
28·08	5N	3	Ti II	87	28·33	(7),	Fe II	27	28·73	(3)
39·51	3An	1	He I	53	43·76	(2)				
43·98†	5	3	He I	53	43·76	(2)				
	1									
45·65	1n	2								
52·50	4	3	?Fe IV	F						
63·46	3	2	Ti II	105	63·64	(40)				
71·78	2	2	Ti II	105	71·89	(30)				
73·79*	11	1	Fe II	27	73·45	(8)				
77·34	12	3	Fe II	21F	77·21,		Fe II	21	77·70	(P)
78·83*	12	2	Fe II	28	78·86,		Fe II	23F	78·95	
87·62:	?1	2								
4199·17	1	1								
4201·11	8	3	Ni II	3F	01·19					
10·91	3	2	Fe II	23F	11·10					
14·37	?1	1								
27·02	3AN	1	Fe II	27	33·17	(11)				
31·30	4	1	Fe II	21F	31·56					
33·16*	18	2	Fe II	27	33·17	(11)				
35·36	3	1								
40·96	4	1								
43·93	30	2	Fe II	21F	43·98					
4244·72	4:	2	Fe II	21F	44·81					

TABLE IIb

Hβ–6900 Å

λ	Int.			Identification				
4862·62	150	H β		61·33				
74·38	4	Fe II	20F	74·49				
85·35	1							
89·58	12	Fe II	4F	89·63				
4898·52	2	Fe II	– F	98·61	($a^2G - b^2D$)			
4905·28	7	Fe II	20F	05·35				
23·80	18	Fe II	42	23·92,		He I	48	21·93
47·26	3	Fe II	20F	47·38				
50·58	4	Fe II	20F	50·74				
73·24	5	Fe II	20F	73·39				
4993·75	?0·5	?Fe II	36	93·36				
5001·34	1					Fe II	36	00·73
05·44 }	3	Fe II	20F	05·52				
06·52 }	2	Fe II	4F	06·65				
09·26	10A	He I	4	15·67				
11·21	0·5	Fe III	1F	11·3				
14·0: }	3n	He I	4	15·67				
18·42 }	40w	Fe II	42	18·43,		Fe II	20F	20·24
43·46	2	Fe II	20F	43·53				
48·03	1·5	Fe II	– F	48·18	($a^2P - c^2D$)			
55·81	?1	?Si II	5	56·0				
60·00	2	Fe II	– F	60·08	($a^2G - b^2D$),	?Fe III	1F	60·3
5072·31	1	Fe II	19F	72·40				
5100·68	?0·5	Fe II	35	00·66		Fe II		00·95
07·78	4	Fe II	18F	07·95				
11·52	6	Fe II	19F	11·63				
32·60	1	Fe II	35	32·67				
46·16	1	Fe II	35	46·12				
54·20	3n					Fe II	35	54·40
5158·48	40	Fe II	18F	58·00,		Fe II	19F	58·81

TABLE IIb (*continued*)

λ	Int.	Identification						
5164·01	6	Fe II	35F	63·94				
68·80	30w	Fe II	42	69·03				
71·91	?4n	?Fe II	35	71·62,	Fe II	–F	72·5	(a^{2}P – c^{2}D)
75·68:	?1n							
81·80	4	Fe II	18F	81·97				
84·66	1?r	Fe II	19F	84·80				
88·38	1	?Ti II	70	88·70				
5197·50	10	Fe II	49	97·57				
5220·02	5	Fe II	19F	20·06				
26·53	1	?Ti II	70	26·53				
34·64	10	Fe II	49	34·62				
37·33	1·5	Cr II	43	37·34				
54·86	1	Fe II	49	54·92				
57·04	1	Fe II	41	56·89				
61·50	15	Fe II	19F	61·61				
64·61	2	Fe II	48	64·80				
68·61	6	Fe II	18F	68·88				
70·49	?1	?Fe III	1F	70·4				
73·14	12	Fe II	18F	73·38				
75·82	12	Fe II	49	75·99				
79·62	?0·5	Cr II	43	79·92				
83·94	5	Fe II	41	84·09,	Fe II	35F	83·1	
5296·67	4	Fe II	19F	96·84				
5313·37	1	Cr II	43	13·59				
16·48	25	Fe II	49	16·61,	Fe II	48	16·78	
25·56	2	Fe II	49	25·56				
28·2	?1							
29·5	?0·5							
33·58	12	Fe II	19F	33·65,	Cr II	43	34·88	
37·05	1·5	?Ti II	69	36·81,	Fe II	48	37·71	
5347·28	2n	Fe II	18F	47·67,	Fe II	49	46·56	

TABLE IIb (*continued*)

λ	Int.	Identification							
5360·51	1								
62·81	6	Fe II	48	62·86,		Fe II	17F	62·06	
5376·35	15	Fe II	19F	76·47					
5408·30	?1n	?Cr II	23	07·6					
12·54	6	Fe II	17F	12·64					
14·32	1n	Fe II	48	14·09					
25·18	3	Fe II	49	25·27					
27·94	1	Fe II		27·83					
33·03	7w	Fe II	18F	33·15,		Fe II	55	32·98	
77·20	3	Fe II	34F	77·25,		Fe II	49	77·67	
5495·76	4	Fe II	17F	95·82					
5527·28	12	Fe II	17F	27·33,		Fe II	34F	27·61	
34·79	9	Fe II	55	34·86					
51·36	2	Fe II	39F	51·31					
56·24	1·5	Fe II	18F	56·31					
59·64	?0·5	?N I	25	60·37					
64·35	0·5	?N I	25	64·37					
80·74	2	Fe II	39F	80·82					
5587·68	1·5	Fe II	39F	88·15,		Fe II	F	87·45	(a^2P-b^2D)
5613·24	1·5	Fe II	39F	13·27					
27·3:	1	Fe II	F	27·25,	(a^2P-b^2D)				
50·14:	1·5n	Fe II	39F	50·94,		Fe II	39F	49·67	
54·72	2	Fe II	17F	54·85					
57·82:	1	Sc II	29	57·87					
5673·18	4	Fe II	F	73·22	(a^2G-c^2G)				
5718·20	?0·5	Fe II	39F	18·2					
47·10	8n	Fe II	34F	46·96					
48·78:	3n	?N II	3F	54·8					
54·52	24	N II	3F	54·8					
57·95	5	?N II	3F	54·8					
5799·1:	?0·5	Fe II	F	99·0	(a^2P-b^2D)				
5835·46	4	Fe II	F	35·44	(a^2G-c^2G)				

Table IIb (*continued*)

λ	Int.	Identification							
5867·86	A5								
70·38	5	Fe II	F	70·0	$(a^2G - a^2I)$				
75·34	40w	He I	11	75·6					
90·48	A2s	Na I	1	89·95					
5896·56	A4s	Na I	1	95·92					
5913·88	1					?Cr II		13·87	
5991·38	7	Fe II	46	91·38					
6008·36	1·5n	Ni II	8F	(07·34)					
30·43:	1								
39·27	2N?d								
40·74	?1								
44·15	3n	Fe II	F	44·10	$(a^2G - a^2I)$,	Fe II	46	44·53	
6084·13	3	Fe II	46	84·11					
6103·75	1N	Fe II	200	03·54					
13·13	1s	Fe II	46	13·33					
29·8:	?0·5	Fe II	46	29·71					
31·6:	?0·5								
47·68	4	Fe II	74	47·74					
49·28	4	Fe II	74	49·24					
6188·43:	3	Fe II	44F	88·55					
6233·14	1n					Fe II		33·52	$(z^4F^0 - c^4D)$
38·42	6	Fe II	74	38·38					
47·52 }	9	Fe II	74	47·56					
49·05 }	2	Fe II		48·92	$(z^4D^0 - c^4D)$				
70·00	1								
91·58	1								
6299·91	2	?O I	1F	00·23					
6305·04:	2n	Fe II	200	05·32					
11·81	7	S III	3F	12·1					
17·96	8	Fe II		17·98	$(z^4D^0 - c^4D)$				
39·86	A5	Si II	2	47·09					
6347·12	4N	Si II	2	47·09					

Table IIb (*continued*)

λ	Int.	Identification							
6352·94	1	Fe II	F	53·1	(a^2D-b^2D)	?O I	1F	63·88	
64·94	4	Ni II	8F	65·52					
69·40 }	3	Fe II	40	69·45					
71·1: }	?1	Si II	2	71·36					
83·55	4	Fe II		83·75	$(z^4D^0-c^4D)$				
6385·32	3	Fe II		85·47	$(z^4D^0-c^4D)$				
6407·14	1	Fe II	74	07·30					
16·88	7	Fe II	74	16·90					
32·52	8	Fe II	40	32·65					
40·28	3	Fe II	15F	40·40					
42·91	2	Fe II		42·97	$(z^4F^0-c^4D)$				
56·24	12	Fe II	74	56·37					
71·58	1								
73·86	2n	Fe II	44F	73·86					
82·04	3n	Fe II	199	82·20,		N I	21	82·74,	81·73
85·10	1·5n	Fe II	F	85·3	(b^4P-a^2S),	N I	21	84·88,	83·75
91·29	3	Fe II		91·28	$(z^4D^0-c^4D)$,	N I	21	91·28	
6493·13	2	Fe II		93·05	$(z^4D^0-c^4D)$				
6506·28	1	Fe II		06·33	$(z^4F^0-c^4D)$,	?N I	21	06·45	
10·94	1					?Fe II	F	11·2	(b^4F-c^2D)
16·07	9	Fe II	40	16·05,		Fe II		17·01	$(z^4D^0-c^4D)$
6563·84	1000	H α							
6612·65:	2n								
66·64	10w	Ni II	2F	66·8					
77·80	25w	He I	46	78·15					
6689·16	1	?Fe II	F	89·4	(a^2D-b^2D)				
6716·52	2	S II	2F	16·42					
6730·30	5n	S II	2F	30·78,		Fe II	31F	29·8	
6809·01	4n	Fe II	31F	09·21					
13·34	3	Ni II	8F	13·73					
73·40	1n	Fe II	43F	73·87,		?Fe II	31F	72·17	
6882·1	1?d								

Following the wavelength:

* a double line measured on DY 646 but not on the plates of lower dispersion. This structure which is found in many strong lines (including some forbidden lines) calls for special investigation and lies outside the scope of the present paper.

† a marked change of intensity between 1961 and 1965 (usually a decrease with time). When two intensities are recorded the first refers to 1961.

: uncertain measure.

The third column (Table IIa) records the number of plates on which the line was measured; in Table IIb this was usually two.

The identifications are recorded as usual in the order: ion, *R.M.T.* number, laboratory wavelength in Å (omitting first two digits) followed (in Table IIa) by the laboratory intensity. Identifications to the right-hand side are regarded as minor contributors to blends.

4. *Representation of elements.* The general conclusions of papers I and II are well confirmed.

The head of the Balmer series was not covered in paper I. On these coudé spectra H 18 is the last strong diffuse emission seen (as compared with H 16 in paper I) but H 22, 27 and 31 are also suspected. Displaced absorption (which probably varies considerably with time and can mask emission lines) is seen prominently as far as H 21 and beyond that seems to persist weakly with sharper absorption up to H 30. Gaviola (1953) found emission up to H 24 and possibly H 28 and absorption to H 18 or 19 on plates taken from 1944 to 1951 and commented on stronger absorption in 1948.

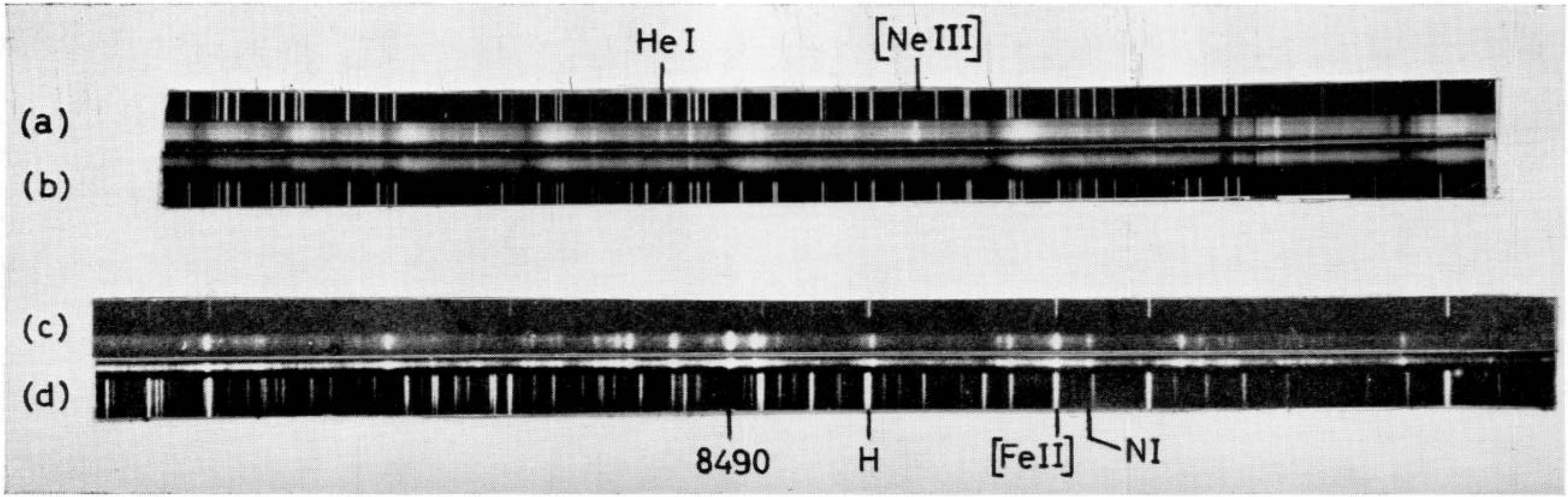
He I emission is much weakened in 1965 (see Plate 1).

N I was found in the infrared in paper II (see Plate 1*c*, *d*). Further lines are identified in the red in Table IIb. An interesting new identification in the ultraviolet is the forbidden line [N I] 3466; a line here was identified by Gaviola (1953) with a blend of Fe I, Mn II and Ni II. Ni II 3465·6 is resolved on Radcliffe spectra, Fe I must be rejected, and Mn 3466·3 with upper E.P. 13·4 V must be a very minor contributor. The [N I] pair at 5200 Å is not found but is expected to be much weaker than 3466, which is known as a feature in auroral spectra.

[N II] 5755 is very strong; it appears to be flanked by shortward and longward companions, possibly originating in the surrounding nebulosity (where [N II] is known to be strong). [N II] 6548, 6584 are known to be present but are lost in the very strong wings of Hα on the coudé plates.

[O I] 6300 may be present, displaced 0·3 Å from its predicted wavelength. If the identification is correct this represents the first evidence for oxygen in η Carinae apart from the permitted line 8446 excited selectively. Unfortunately the companion line [O I] 6364 is masked by a line of [Ni II]. Evidence for the absence of [O II] and [O III] is strengthened by the coudé material.

[Ne III] 3868, 3967 provide the most striking example of change between 1961 and 1965, being invisible on DZ 1310 (see Plate 1). The lines seen to have reappeared in moderate strength on cassegrain spectra of 1966.



Coudé spectra of Eta Carinae. (*a*) 1962 *May* 20, (*b*) 1965 *March* 19. *Note variations of marked lines He I* 3819, [*Ne III*] 3868. (*c*) 1960 *May* 18, (*d*) 1960 *May* 16; *infra-red, with lines* 8490 (*unidentified*), *H* 8545, [*Fe II*] 8617, *N I* 8629.

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Mg I 3838, as in paper I, may be present but the identification is doubtful and the line probably is a displaced component of H 9; the other members of the triplet fail to appear (perhaps due to absorption by H 9) and the 'b' triplet is also absent.

[S II]. 6716, 6730 of 2F both appear in Table IIb, apparently strengthened since 1952. 4068, 4076 of 1F are strong, as before, but the unidentified line of paper I at 4064 does not appear on coudé spectra. This was probably a displaced component of [S II] 4076, which is strong in the surrounding halo. Its non-appearance on the later plates may be due to a physical change or (less likely) a different orientation of the coudé slit.

[Cl II]. No lines are found, the negative evidence being far stronger than in paper I, but predicted wavelengths are still uncertain.

[Ar III]. 2F and 3F are not found, and the sole evidence continues to rest on the line 7135 (1F).

Mn II. A few lines appear in the ultraviolet. No such lines were recorded in paper I.

Fe II, Ni II. See next section. The very strong Fe I lines in ultraviolet fail to appear.

[Cu II]. The line 3805 is confirmed.

Zr II. The strongest lines in ultra-violet fail to appear.

5. *Intensities of [Fe II] lines.* Garstang's (1962) transition probabilities have been invaluable for identifying numerous faint lines of [Fe II]. Garstang compared observed intensities in four multiplets in η Carinae and other objects with his values of $(2J+1)A$, J being the inner quantum number of the upper state.

The observational data regarding [Fe II] in η Carinae is now more extensive for the range of wavelengths 3100–9000 Å (the weakest portion being from 6850 to 7100 Å). Thus a more detailed comparison is warranted.

Table III therefore lists *all* [Fe II] multiplets and transitions in the relevant range with significant values of $(2J+1)A$. We write R_m or R_q for this quantity according to whether the relevant transition is magnetic dipole or electric quadrupole. Following Garstang, multiplets are arranged in order of increasing *upper* E.P. (rather than lower E.P. as in the *R.M.T.*) The upper E.P. is given in the first column together with the *R.M.T.* number. Within each multiplet the order is of decreasing R.

The wavelengths corresponding to the transitions were not given by Garstang. They are listed (to 0·1 Å) for the transitions quoted in Table III, being taken from the *R.M.T.* when available, but in all other cases they have been derived by the writer from Kayser's Tables.

The η Carinae intensities are all visual estimates by the writer. Intensities in brackets refer to a blended line; when followed by b the blending line predominates, and m means a masked line contributing almost nothing to the observed intensity. The adjacent column carries a symbol to indicate the relevant region of wavelength: A, ultraviolet coudé (Table IIa), B photographic cassegrain (paper I), C visual coudé (Table IIb), D infrared coudé (paper II). It must be emphasized that the intensity scales in different regions are quite different, as can be seen when duplicate estimates are quoted. However, within a given multiplet of course it is rare to find lines belonging to different regions. An asterisk in the last column refers to a note at the end of the Table.

TABLE III

[Fe II] *intensities in η Carinae compared with Garstang's transition probabilities*

Transition *R.M.T.* High E.P.	J	λ	R_m	R_q	η Carinae int.		Regic
a^4F-a^4P							
(13F)	$4\frac{1}{2}-2\frac{1}{2}$	8617·0		·102	15?v		D
1·7	$3\frac{1}{2}-1\frac{1}{2}$	8891·9		·040	3		D
	$1\frac{1}{2}-1\frac{1}{2}$	9267·5		·020			
a^4F-a^2G							
(14F)	$4\frac{1}{2}-4\frac{1}{2}$	7155·1	1·5		20		D
2·0	$3\frac{1}{2}-4\frac{1}{2}$	7452·5	·48		12		D
	$3\frac{1}{2}-3\frac{1}{2}$	7172·0	·45		4		D
	$2\frac{1}{2}-3\frac{1}{2}$	7388·2	·34		9		D
	$4\frac{1}{2}-3\frac{1}{2}$	6896·2	·042				
	$2\frac{1}{2}-4\frac{1}{2}$	7686·2			2		D
a^4F-a^2P							
(15F)	$2\frac{1}{2}-1\frac{1}{2}$	6440·4	·092		6,	3	B,
2·3	$1\frac{1}{2}-1\frac{1}{2}$	6558·5	·064		m,	m	B,
a^4F-a^2D							
(17F)	$3\frac{1}{2}-2\frac{1}{2}$	5527·3	1·62		25,	12	B,
2·6	$2\frac{1}{2}-1\frac{1}{2}$	5412·6	1·08		(15),	6	B,
	$1\frac{1}{2}-1\frac{1}{2}$	5495·8	·56		8N,	4	B,
	$2\frac{1}{2}-2\frac{1}{2}$	5654·8	·18		2		C
	$1\frac{1}{2}-2\frac{1}{2}$	5745·7	·08				
a^6D-b^4P							
(4F)	$3\frac{1}{2}-2\frac{1}{2}$	4889·6	2·16		20,	12	B,
2·7	$2\frac{1}{2}-1\frac{1}{2}$	4728·1	1·92		20		B
	$1\frac{1}{2}-\frac{1}{2}$	4639·7	·98		15		B
	$\frac{1}{2}-1\frac{1}{2}$	4798·2	·33		5		B
	$\frac{1}{2}-\frac{1}{2}$	4664·4	·30		6		B
	$1\frac{1}{2}-2\frac{1}{2}$	5006·6	·16		(10)b,	2	B,
	$1\frac{1}{2}-1\frac{1}{2}$	4772·1	·10		?2		B
	$2\frac{1}{2}-2\frac{1}{2}$	4958·2	·03				
a^4F-b^4P							
(18F)	$4\frac{1}{2}-2\frac{1}{2}$	5273·4		2·2	(60),	12	B,
2·7	$3\frac{1}{2}-1\frac{1}{2}$	5158·0		1·20	(45),	(40)	B,
	$2\frac{1}{2}-1\frac{1}{2}$	5268·9		·76	(50)b,	6	B,
	$1\frac{1}{2}-\frac{1}{2}$	5182·0		·68	11,	4	B,
	$3\frac{1}{2}-2\frac{1}{2}$	5433·2		·66	18	(7)	B,
	$2\frac{1}{2}-\frac{1}{2}$	5108·0		·48	11,	4	B,
	$1\frac{1}{2}-1\frac{1}{2}$	5347·7		·23	(6),	(2)	B,
	$2\frac{1}{2}-2\frac{1}{2}$	5556·3		·13	?4n,	1·5	B,
	$1\frac{1}{2}-2\frac{1}{2}$	5644·0		·015			
a^4D-b^4P							
(30F)	$3\frac{1}{2}-2\frac{1}{2}$	7764·7	·17		1·5		D
2·7	$2\frac{1}{2}-2\frac{1}{2}$	8037·3	·055				
	$1\frac{1}{2}-1\frac{1}{2}$	7613·2	·048				
	$1\frac{1}{2}-2\frac{1}{2}$	8228·2	·047		m		D

TABLE III (*continued*)

.tion .*M.T.* E.P.	J	λ	R_m	R_q	η Carinae int.		Region
a^{4}H							
	$4\frac{1}{2}-6\frac{1}{2}$	5158·8		6·2	(45),	(40)	B, C
	$3\frac{1}{2}-5\frac{1}{2}$	5261·6		3·7	20,	15	B, C
	$2\frac{1}{2}-4\frac{1}{2}$	5333·6		2·6	25,	12	B, C
	$1\frac{1}{2}-3\frac{1}{2}$	5376·5		2·1	25,	15	B, C
	$4\frac{1}{2}-5\frac{1}{2}$	5111·6		1·20	13,	6	B, C
	$3\frac{1}{2}-4\frac{1}{2}$	5220·1		1·10	10,	5	B, C
	$2\frac{1}{2}-3\frac{1}{2}$	5296·8		·73	(9)	4	B, C
	$4\frac{1}{2}-4\frac{1}{2}$	5072·4		·22	5,	1	B, C
	$3\frac{1}{2}-3\frac{1}{2}$	5184·8		·17	?4n,	1	B, C
	$4\frac{1}{2}-3\frac{1}{2}$	5039·1		·013			
- b^{4}F							
	$4\frac{1}{2}-4\frac{1}{2}$	4416·3	4·6			(50N)	B
	$3\frac{1}{2}-3\frac{1}{2}$	4458·0	2·3			18	B
	$2\frac{1}{2}-2\frac{1}{2}$	4488·8	·90			(15)	B
	$3\frac{1}{2}-4\frac{1}{2}$	4492·6	·60		7,	(15)b	A, B *
	$2\frac{1}{2}-3\frac{1}{2}$	4514·9	·53			(16)b	B
	$4\frac{1}{2}-3\frac{1}{2}$	4382·8	·44			4	B
	$3\frac{1}{2}-2\frac{1}{2}$	4432·4	·32			4	B
	$1\frac{1}{2}-2\frac{1}{2}$	4528·4	·28		4,	3	A, B
	$1\frac{1}{2}-1\frac{1}{2}$	4509·6	·23		?0·5,	(15)b	A, B
	$2\frac{1}{2}-1\frac{1}{2}$	4470·3	·12		3:	m	A, B *
	$\frac{1}{2}-1\frac{1}{2}$	4533·0	·06		?1·5,	?2	A, B
- b^{4}F ')							
	$4\frac{1}{2}-4\frac{1}{2}$	4814·6		4·0	25		B
	$3\frac{1}{2}-3\frac{1}{2}$	4905·3		1·8	15,	7	B, C
	$4\frac{1}{2}-3\frac{1}{2}$	4774·7		1·04	10		B
	$3\frac{1}{2}-2\frac{1}{2}$	4874·5		1·02	10,	4	B, C
	$2\frac{1}{2}-2\frac{1}{2}$	4973·4		·84	10,	5	B, C
	$1\frac{1}{2}-1\frac{1}{2}$	5020·2		·72	(70)b,	(40)b	B, C
	$2\frac{1}{2}-1\frac{1}{2}$	4950·7		·68	10,	4	B, C
	$2\frac{1}{2}-3\frac{1}{2}$	5005·5		·57	(10),	3	B, C
	$3\frac{1}{2}-4\frac{1}{2}$	4947·4		·50	7,	3	B, C
	$1\frac{1}{2}-2\frac{1}{2}$	5043·5		·39	8:	2	B, C
	$3\frac{1}{2}-1\frac{1}{2}$	4852·7		·088	2,		B
	$4\frac{1}{2}-2\frac{1}{2}$	4745·5		·078	?2		B
	$2\frac{1}{2}-4\frac{1}{2}$	5049·3		·007			
– b^{4}F ')							
	$3\frac{1}{2}-4\frac{1}{2}$	6809·2	·25		10,	4n	B, C
	$3\frac{1}{2}-3\frac{1}{2}$	6729·8	·136		8,	(5n)	B, C
	$2\frac{1}{2}-2\frac{1}{2}$	6872·2	·132		(?6),	(1n)	B, C
	$1\frac{1}{2}-1\frac{1}{2}$	6966·3	·104				B, C
	$\frac{1}{2}-1\frac{1}{2}$	7048·0	·064				
– a^{6}S ')							
	$4\frac{1}{2}-2\frac{1}{2}$	4287·4		6·7	50N		B
	$3\frac{1}{2}-2\frac{1}{2}$	4359·3		4·9	(60)		B
	$2\frac{1}{2}-2\frac{1}{2}$	4413·8		3·5	50N		B
	$1\frac{1}{2}-2\frac{1}{2}$	4452·1		2·2	20		B
	$\frac{1}{2}-2\frac{1}{2}$	4474·9		1·1	12		B

TABLE III (*continued*)

Transition *R.M.T.* High E.P.	*J*	λ	R_m	R_q	Carinae int.		Regi
a^{6}D – a^{4}G							
(8F)	$4\frac{1}{2}-4\frac{1}{2}$	3874·1	·14		0·7		A
(3·2)	$3\frac{1}{2}-3\frac{1}{2}$	3905·6	·064		2?d,	(1n)	A,
	$3\frac{1}{2}-4\frac{1}{2}$	3932·7	·026				
a^{4}F – a^{4}G							
(21F)	$4\frac{1}{2}-5\frac{1}{2}$	4244·0		10·8	30,	(45N)	A,
3·2	$3\frac{1}{2}-4\frac{1}{2}$	4276·8		6·5		20	
	$1\frac{1}{2}-2\frac{1}{2}$	4358·4		4·4		(60)b	
	$2\frac{1}{2}-3\frac{1}{2}$	4319·6		4·2		15	
	$2\frac{1}{2}-4\frac{1}{2}$	4352·8		3·1		(20)b	
	$3\frac{1}{2}-5\frac{1}{2}$	4346·8		2·5		(8)	
	$1\frac{1}{2}-3\frac{1}{2}$	4372·4		2·2		9	
	$3\frac{1}{2}-3\frac{1}{2}$	4244·8		2·0	4:	(45N)b	A,
	$2\frac{1}{2}-2\frac{1}{2}$	4305·9		1·9		8	
	$4\frac{1}{2}-4\frac{1}{2}$	4177·2		1·4	12,	10	A,
	$3\frac{1}{2}-2\frac{1}{2}$	4231·6		·14	4,	m	A,
	$4\frac{1}{2}-3\frac{1}{2}$	4146·6		·07		?2n	A,
a^{4}D – a^{4}G							
(33F)	$2\frac{1}{2}-3\frac{1}{2}$	5683·6	·022				
3·2	$3\frac{1}{2}-3\frac{1}{2}$	5545·9	·021				
a^{6}D – b^{2}P							
(9F)	$2\frac{1}{2}-1\frac{1}{2}$	3979·8	·017		?1s,	(1)	A,
3·2	$1\frac{1}{2}-\frac{1}{2}$	3834·7	·004				
a^{4}F – b^{2}P							
(22F)	$2\frac{1}{2}-1\frac{1}{2}$	4356·1		·032	m		B
3·2	$1\frac{1}{2}-\frac{1}{2}$	4197·8		·020			B
	$1\frac{1}{2}-1\frac{1}{2}$	4409·9		·017	m		B
a^{4}D – b^{2}P							
(34F)	$2\frac{1}{2}-1\frac{1}{2}$	5747·0	1·48		8n		C
3·2	$1\frac{1}{2}-\frac{1}{2}$	5477·2	·88		3		C
	$\frac{1}{2}-\frac{1}{2}$	5527·6	·24		(12)b		C
	$\frac{1}{2}-1\frac{1}{2}$	5901·3	·16				C
a^{4}F – b^{2}H							
(23F)	$4\frac{1}{2}-5\frac{1}{2}$	4114·5		·54	6,	7	A,
3·2	$3\frac{1}{2}-5\frac{1}{2}$	4211·1		·29	3,	3	A,
	$2\frac{1}{2}-4\frac{1}{2}$	4251·4		·087	1		A
a^{4}D – a^{2}F							
(35F)	$3\frac{1}{2}-3\frac{1}{2}$	5163·9	2·56		10,	6	B,
3·4	$2\frac{1}{2}-3\frac{1}{2}$	5283·1	1·12		(10),	(5)b	B,
	$2\frac{1}{2}-2\frac{1}{2}$	5199·2	·11		m,		B,
	$1\frac{1}{2}-2\frac{1}{2}$	5278·4	·072		m		
a^{2}G – a^{2}F							
(42F)	$4\frac{1}{2}-3\frac{1}{2}$	8715·8		·40	2		D
3·4	$3\frac{1}{2}-2\frac{1}{2}$	8885·7		·072			

TABLE III (*continued*)

nsition *R.M.T.* h E.P.	*J*	λ	R_m	R_q	η Carinae int.		Region
$-b^2G$							
F)	4½ − 4½	3505·8		·032			
) $-b^2G$							
	3½ − 3½	4383·0	·040				
; $-b^2G$							
F)	4½ − 4½	6873·9		·98	?6,	1n	B, C
	3½ − 3½	6944·9		·70	8		B
	3½ − 4½	7131·1		·11			
	4½ − 3½	6700·7		·10			
) $-b^4D$							
F)	4½ − 3½	3175·4	1·76		0·5		A
	2½ − 2½	3254·2	·72				
	1½ − 1½	3277·6	·64		m		A
	½ − ½	3289·5	·44		(2)		A
	1½ − 2½	3275·0	·34				
	½ − 1½	3289·9	·24				
ˀ $-b^4D$							
·F)	4½ − 3½	3376·2		5·8	7		A
)	3½ − 2½	3452·3		2·2	3		A
	2½ − 2½	3501·6		2·04	4		A
	3½ − 3½	3441·0		1·92	(4)		A
	1½ − 1½	3539·2		1·52	(4)		A
	3½ − 1½	3455·1		1·44	(3)		A
	4½ − 2½	3387·1		1·20			A
	2½ − ½	3504·0		1·04	(5N)		A
	2½ − 1½	3504·5		·84	(5N)b		A
	1½ − ½	3538·7		·80	(4)		A
	2½ − 3½	3490·0		·28	1·5		A
D $-b^4D$							
5F)	3½ − 2½	4266·3	·144		?0·5		A
)	2½ − 3½	4329·4	·136				
P $-b^4D$							
9F)	2½ − 3½	5551·3		1·04	6,	2	B, C
)	2½ − 2½	5580·8		·78	4N,	2	B, C
	1½ − 3½	5613·3		·58	6N,	1·5	B, C
	½ − 2½	5718·2		·40	?4,	?0·5	B, C
	1½ − ½	5649·7		·32	6N,	(1·5)	B, C
	1½ − 1½	5650·9		·30	(6N),	(1·5)	B, C
	2½ − 1½	5588·2		·29	(6N),	(1·5)	B, C
	½ − 1½	5725·9		·16			
	2½ − ½	5586·9		·04			
F $-b^2F$							
7F)	4½ − 3½	3318·4	·34	·003			
9	1½ − 2½	3484·0	·28	·014	(·15)b		A

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Table III (*continued*)

ransition *R.M.T.* igh E.P.	*J*	λ	R_m	R_q	η Carinae int.		Regio
^{4}D – b^{2}F							
37F)	$3\frac{1}{2}-3\frac{1}{2}$	4157·9	·14				
3·9							
^{2}G – b^{2}F							
(44F)	$4\frac{1}{2}-3\frac{1}{2}$	6188·6	·23	·80	7,	3	B, C
3·9	$3\frac{1}{2}-2\frac{1}{2}$	6473·9	·17	·21		2n	B, C
	$3\frac{1}{2}-3\frac{1}{2}$	6396·3	·36	·001			
a^{2}H – b^{2}F							
(49F)	$5\frac{1}{2}-3\frac{1}{2}$	8649·1		·25	1·5		D
3·9	$4\frac{1}{2}-2\frac{1}{2}$	9083·4		·18			
a^{2}G – a^{2}I							
	$4\frac{1}{2}-6\frac{1}{2}$	5870·0		1·96	m,	5	B, C
4·1	$3\frac{1}{2}-5\frac{1}{2}$	6044·1		1·32	(10)n,	3n	B, C
a^{2}H – a^{2}I							
	$5\frac{1}{2}-6\frac{1}{2}$	7975·3		·97	4		D
4·1	$4\frac{1}{2}-5\frac{1}{2}$	8398·2		·72			
a^{4}H – a^{2}I							
	$6\frac{1}{2}-6\frac{1}{2}$	8600·5	1·36				
4·1	$5\frac{1}{2}-6\frac{1}{2}$	8734·9	·55				
a^{2}G – c^{2}G							
	$4\frac{1}{2}-4\frac{1}{2}$	5673·2		3·0	8,	4	B, C
4·1	$3\frac{1}{2}-3\frac{1}{2}$	5835·4		2·6	8,	4	B, C
	$3\frac{1}{2}-4\frac{1}{2}$	5847·3		·33			
a^{2}D – c^{2}G							
	$2\frac{1}{2}-4\frac{1}{2}$	7720·2		·29			
4·1							
a^{4}H – c^{2}G							
	$5\frac{1}{2}-4\frac{1}{2}$	8306·2	1·5		2b		D
4·1	$4\frac{1}{2}-3\frac{1}{2}$	8387·2	1·2				
	$3\frac{1}{2}-3\frac{1}{2}$	8479·8	·80		(0·7)		
b^{4}F – c^{2}G							
	$4\frac{1}{2}-4\frac{1}{2}$	9231·7	2·1				
4·1	$3\frac{1}{2}-3\frac{1}{2}$	9351	·80				
a^{4}D – b^{2}D							
	$3\frac{1}{2}-2\frac{1}{2}$	3532·8	1·20		?1n		A
4·5	$\frac{1}{2}-1\frac{1}{2}$	3664·7	·56				
	$1\frac{1}{2}-1\frac{1}{2}$	3642·5	·28				
a^{2}G – b^{2}D							
	$4\frac{1}{2}-2\frac{1}{2}$	4898·6		4·9	3,	2	B,
4·5	$3\frac{1}{2}-1\frac{1}{2}$	5060·1		2·5	(7),	2	B,
	$3\frac{1}{2}-2\frac{1}{2}$	5027·9		·52			

TABLE III (*continued*)

sition *R.M.T.* h E.P.	*J*	λ	R_m	R_q	η Carinae int.		Region
−b²D							
	1½−1½	5627·2		·60	?8N,	1	B, C
	½−1½	5799·0		·32		?0·5	B, C
	1½−2½	5587·4		·22	(6N),	(1·5)	B, C
−b²D							
	2½−2½	6353·1		1·02	?8,	1	B, C
	1½−2½	6689·4		·26		1	C
	2½−1½	6404·6		·24			
	1½−1½	6746·5		·22	(8)		B
−a²S							
	1½−½	6485·3	1·46		10,	1·5	B, C
	½−½	6746·9	·40		(8)		B
−a²S							
	1½−½	8739·1	·46				
	½−½	9711	·46				
−c²D							
	3½−1½	4576·4		1·9	m,	m	A, B
	4½−2½	4479·1		1·4	m		A
−c²D							
	1½−2½	5048·2		2·5	6:,	1·5	B, C
	½−1½	5172·5		·84		(?4n)	B, C
	½−2½	5186·0		·66			
	1½−1½	5035·4		·44			
F−c²D							
	2½−1½	6544·8	·76		m		C
	3½−2½	6511·2	·64		1		C

Notes to Table III

13F	8617·0	The [Fe II] line is probably the main component of the blend with an unidentified line (shortward).
14F	7172·0 7686·2	Reference to the *Revised Rowland Table* shows that numerous atmospheric lines occur in the solar spectrum near 7172; other members of the multiplet are relatively free. The relative weakness in η Carinae compared with Garstang's intensities is probably to be ascribed to telluric absorption. Garstang's intensity for the line 7686 suggests that another identification should be sought for the observed line.
4F	5006·6	The cassegrain blend is resolved at coudé dispersion. It is important to note that the measured wavelength suggests no contribution from [O III] 5006·84 (ref. Table IIb).

6F	4492·6 4470·3	These lines appear clearly resolved from strong companions at coudé dispersion. 4509·6 and 4533·0 appear doubtfully as very weak lines. All these lines lie beyond the range of Table IIa; intensities were assigned after special examination of plates DZ 658, 1310.
31F	6966·3	The wavelength is unfavourable for recording this line with any of the emulsions used.
8F	3874·1	This line appears clearly as a weak line on DZ 658 but was missed on measurement and therefore is omitted in Table IIa. The line observed at 3905 Å may be only partly due to [Fe II].
9F	3979·8	The identification is unsatisfactory. The contribution of Cr II 3979·51 (with more accordant wavelength) must be small because the upper state is 8·75 V, and the stronger line Cr II 3865·6 does not appear.
22F	4409·9	The line is masked by the strong violet-displaced component of [Fe II] 4414. Identification with 22F in paper I should be withdrawn.
23F	4211·1 4251·4	Identification with Fe III of 4211 in paper I should be withdrawn. 4251 appears clearly on DZ 658.
26F	3387·1	This line may be represented by a feature (?2N) at about 3386·9, missed in the original measures.
36F	4266·3	This line is doubtfully present on DZ 658. Identifications of $\lambda\lambda$ 4248, 4347 in this multiplet in paper I should be withdrawn in the light of Garstang's calculations.
39F	5613·3 5718·2	These two lines, not listed in *R.M.T.*, should be relatively strong according to Garstang. Coudé wavelengths and intensities agree excellently with predictions.
44F	6473·9	This line, missed at cassegrain, appears at coudé in good agreement with predictions.
49F	8649·1	A coudé line, attributed doubtfully in paper II to a blend of [Ti II] and [Sc II], may perhaps be this line, although the observed wavelength 8648·70 is discrepant.
a^2G-a^2I	5870·0 6044·1	A coudé line, appearing in the wing of He 5876 at 5870·38, could not be detected at cassegrain dispersion. Garstang's intensity indicates that the line observed at 6044·15 is dominated by [Fe II] with Fe II 6044·53 a minor blend.
a^2H-a^2I	7975·3	This identification was suggested in paper II but [Ti II] was regarded as possibly the major contributor. The latter suggestion should perhaps now be withdrawn.
a^2G-c^2G	5673·2 5835·4	The coudé wavelengths and intensities strongly support the identifications of these lines suggested in paper I.
a^1H-c^2G	8306·0	A coudé line was observed at 8306·5 and is rather too strong to be entirely due to H 8306·11.

a^4D-b^2D	3664·7	This line, expected to be very weak, is in any case masked by a Balmer line. Struve & Swings (1940) claimed to have observed this line and λ 3625·8 of this multiplet in WY Gem. The latter line was later identified by Swings (1943) with Ni II 5F. The marginal observation of 3532·8 in η Carinae probably represents the first true observation of this multiplet.
a^2G-b^2D	4898·6 5060·1	These are two hitherto well-known unidentified lines. The coudé data are in excellent accord with predictions. The identifications were noticed by the writer soon after he received Garstang's paper; they have been independently noticed by Swings (private communication).
a^2P-b^2D	5627·2	This identification suggested in paper I is confirmed and another line (5799) appears on coudé spectra.
a^2D-b^2D	6353·1 6689·4	These two strongest lines, according to Garstang, are both apparently present on coudé spectra. 6353 was recorded in paper I, unidentified.
b^4P-a^2S	6485·3	The identification could hardly have been suggested without Garstang's transition probability.
a^2G-c^2D	4479·1	This line clearly appears on DZ 658. λ 4576·4 is masked.
a^2P-c^2D	5048·2	The identification suggested in paper I is well confirmed by the coudé data and by Garstang's prediction.
b^4F-c^2D	6511·2	The strongest line of this multiplet (6545) is masked by Hα. Although 6511 is hardly likely to appear according to predicted intensity, the wing of Hα may have served to bring it up marginally.

It is immediately apparent that within any multiplet the general run of observed intensities follows very closely Garstang's calculated values of R_m or R_q.

The table should be of general utility in identification of [Fe II] lines in any object throughout the spectral range 3100–9000 Å. If a richer source than η Carinae should be found or the range of wavelengths extended further, then Garstang's tables should be consulted again. Further, an object with higher excitation temperature than η Carinae (see Section 7) might show some lines omitted from Table III.

We conclude that the following 33 [Fe II] multiplets are definitely present in η Carinae: 4F, 6F, 7F, 11F, 13F, 14F, 15F, 17F, 18F, 19F, 20F, 21F, 23F, 26F, 30F, 31F, 34F, 35F, 39F, 42F, 43F, 44F, 49F, a^2G-a^2I, a^2H-a^2I, a^2G-c^2G, a^2G-b^2D, a^2P-b^2D, a^2D-b^2D, b^4P-a^2S, a^2G-c^2D, a^2P-c^2D. Six of these have not been reported before.

Doubtfully present are: 8F, 9F, 36F, a^4H-c^2G, a^4D-b^2D, b^4F-c^2D.

Probably absent are: 2F, 10F, 22F, 25F, 27F, 33F, 37F, etc.

The coudé spectra, combined with Garstang's probabilities, have led to the abandonment of a number of idenifications previously suggested in η Carinae or other objects. In particular there does not seem to be any clear-cut case of a sextet–doublet intercombination of [Fe II], with the one doubtful exception of 9F possibly represented by the weak line 3979·8.

In paper I, one multiplet (a^2P-c^2D) was found with upper state only 0·04 V below the lowest odd state. This result is confirmed and another such multiplet has now been found.

TABLE IV

[Ni II] intensities compared with Garstang's transition probabilities

Transition *R.M.T.* High E.P.	*J*	λ	R_m	R_q	η Carinae int.		Region
a^{2}D – a^{2}F							
(2F)	$2\frac{1}{2}-3\frac{1}{2}$	7737·9		1·12		25w	D
1·8	$1\frac{1}{2}-2\frac{1}{2}$	7411·6		·66		15	D
	$2\frac{1}{2}-2\frac{1}{2}$	6666·8		·37	10,		C,
	$1\frac{1}{2}-3\frac{1}{2}$	8301·0		·06			D
a^{2}D – b^{2}D							
(3F)	$2\frac{1}{2}-2\frac{1}{2}$	4326·3	7·2	1·4	6		B
2·9	$1\frac{1}{2}-1\frac{1}{2}$	4485·52	·39	2·0	2·5		B
	$2\frac{1}{2}-1\frac{1}{2}$	4201·2	·16	·20	7		B
	$1\frac{1}{2}-2\frac{1}{2}$	4628·1	·06	·54	m		B
a^{4}F – b^{2}D							
(7F)	$2\frac{1}{2}-1\frac{1}{2}$	7307·8	1·6	·01	(5)b		D
2·9	$1\frac{1}{2}-1\frac{1}{2}$	7613·0	·76	·01			D
	$3\frac{1}{2}-2\frac{1}{2}$	7256·2	1·02	·02	4		D
	$4\frac{1}{2}-2\frac{1}{2}$	6794·4		·12			
a^{2}D – ^{4}P							
(4F)	$2\frac{1}{2}-2\frac{1}{2}$	3993·2	2·5	2·5	8,	6	A, I
3·1	$1\frac{1}{2}-1\frac{1}{2}$	4294·1	·84	·56		m	I
	$1\frac{1}{2}-2\frac{1}{2}$	4248·9	·046	·84		(6n)	I
	$2\frac{1}{2}-1\frac{1}{2}$	4033·1	·14	·18	2,	(2)b	I
^{4}F – ^{4}P							
(8F)	$3\frac{1}{2}-2\frac{1}{2}$	6365·5	1·3		4		C
3·1	$2\frac{1}{2}-1\frac{1}{2}$	6813·7	·48		3		C
a^{2}D – ^{2}P							
(5F)	$2\frac{1}{2}-1\frac{1}{2}$	3438·9		21·6	6		A
3·6	$1\frac{1}{2}-\frac{1}{2}$	3559·4		7·4	4		A
	$2\frac{1}{2}-\frac{1}{2}$	3378·2		6·0	3		A
	$1\frac{1}{2}-1\frac{1}{2}$	3626·9		4·4	5		A
a^{2}D – ^{2}G							
(6F)	$2\frac{1}{2}-4\frac{1}{2}$	3076·1		44	1		A
4·0	$1\frac{1}{2}-3\frac{1}{2}$	3223·16		24	2·5		A
^{4}F – ^{2}G							
(10F)	$4\frac{1}{2}-4\frac{1}{2}$	4147·3	3·5				
4·0	$3\frac{1}{2}-3\frac{1}{2}$	4310·5	1·4				

Notes to Table IV

2F	8301·0	This line fails to appear on coudé spectra and should not do so according to Garstang's intensities. The cassegrain line at 8305, previously attributed to [Ni II] is now identified partly with [Fe II] a^{4}H – c^{2}G (see Table III).
3F	**4201·2**	The observed intensity appears to be too strong, perhaps indicating an unidentified blend.

7F	7613·0	The failure to observe this line must be due to the superposition of strong atmospheric absorption at this wavelength.
4F	4294·1	This line appears to be partly masked by displaced absorption due to Ti II 4300.
8F	6365·5 6813·7	Both lines appear on coudé spectra, only the former having appeared on cassegrain. Despite rather large discrepancies in wavelength (perhaps due to errors in Ni II energy levels), Garstang's intensities make the identifications practically certain.
5F		All coudé wavelengths of these lines (not available on cassegrain spectra) confirm the predictions based on Shenstone's revision of low Ni II levels.
6F	3076·1	The last coudé line visible towards the ultraviolet. Its true intensity must be greater than that of 3223, in accordance with Garstang's predictions. It is noteworthy that the only transition in this multiplet listed in *R.M.T.* is still weaker according to Garstang and does not appear.

5. *[Fe III] in η Carinae.* [Fe III] is definitely represented in η Carinae by fairly strong lines 4658, 4701, 4733 of multiplet 3F. According to Garstang (1957) the strongest lines of 1F should be 5270, 5011, and 4930. The first line appeared resolved in Table IIb, in 1952 the second was probably masked by displaced He I absorption but is recorded weakly on the later coudé plates, while the third seems to be present in paper I (where it was left unidentified); it was not detected on coudé spectra whose general limiting intensity in this region lies above that of the cassegrain spectra.

6. *[Ni II] in η Carinae.* Table IV presents observed and predicted intensities in 7 multiplets of [Ni II] in the same form as Table III; 8F and 6F seem to be new. Again the agreement with Garstang is very good, with the one exception of 4201 in 3F; perhaps this line is affected by an unidentified blend.

7. *Excitation temperature.* Our visual estimates of intensity I are some unknown function of the true intensity I_t which should be proportional to $N \times R$ where N is the number of Fe II ions in the relevant upper state. If we ignore variations in ionization in the optical column and assume the distribution of ions in the states to be according to Boltzmann's law with excitation temperature T, then $\log I_t = \log R - (5040E/T) + \text{constant}$, where E is the upper excitation potential in volts.

Plots of $\log I$ against $\log R$ for each multiplet show roughly linear correlation. For a group of multiplets lying in the same general range of wavelengths and with roughly the same values of E we find R_0 corresponding to a given value of I, one value of R_0 for each group.

With constant I (or I_t) we have

$$\log R_0 = \frac{5040E}{T} + \text{constant}$$

$\log R_0$ is plotted against E in Fig. 1. Different ranges of wavelengths are distinguished by different symbols. The constant in the above equation varies according to the region and the infrared and ultraviolet symbols have been consequently adjusted up or down by constant amounts in the same manner as fitting curves of growth.

In the course of the work magnetic dipole and electric quadrupole transitions were distinguished but the observed intensities fitted R_m and R_q equally well and therefore this distinction is not made in the figure.

Fig. 1 shows the slope of the relation between R_0 and E corresponding to values of $T = 7000$, 8500 and 10 000 °K. It is unlikely that the excitation temperature lies outside this range, and we may conclude that $T = 8500 \pm 1500$ °K. Quantitative measures would of course increase greatly the accuracy of the determination.

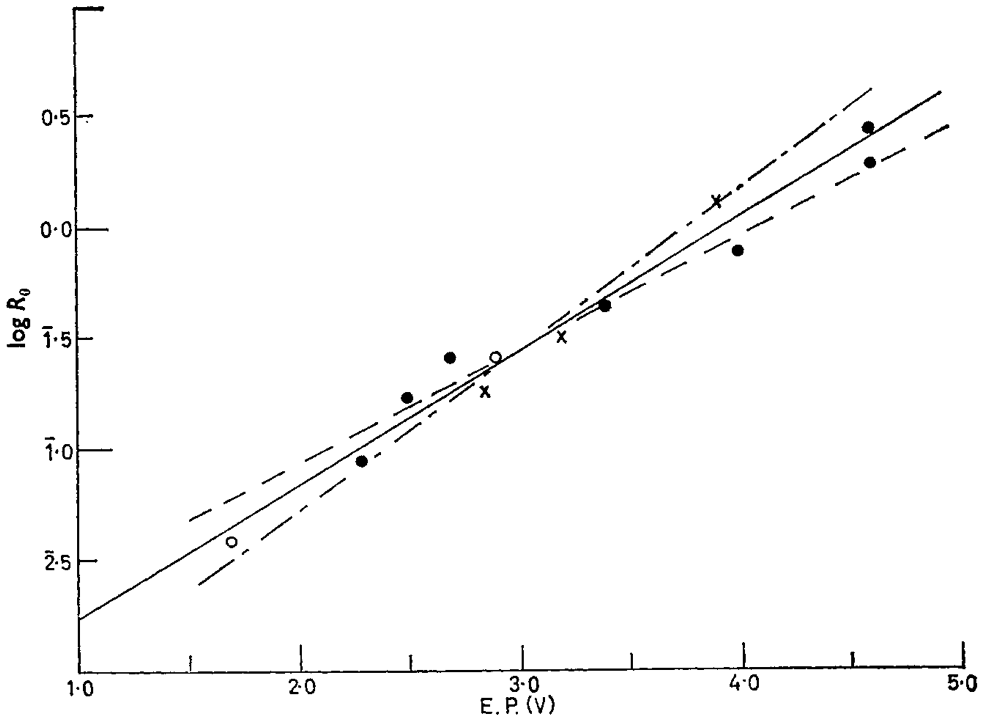

Fig. 1. *Excitation temperature of Eta Car from (Fe II) lines, (see text). Filled circles 5000–6800 Å, crosses 3300–5000 Å, open circles 7200–8900 Å. The slope of the solid line corresponds to $T = 8500$ °K, of the other two to 7000 and 10 000 °K.*

An attempt was made to analyse the [Ni II] intensities for excitation temperature in the same way, but the scatter was greater and the number of usable multiplets too few. All that can be said is that the results are not inconsistent with the above.

8. *Variations in structure and intensity of lines.* Although the general character of the spectrum of η Carinae has remained essentially unchanged during the past 20 years or more, the helium lines as first noted by Gaviola (1953) are subject to changes in intensity; the simultaneous weakening of [Ne III] in 1965 (Plate 1) has not been noted before, but appears to be an extreme instance. Further we have evidence that [S II] 6717, 6730 was probably stronger in 1961 than in 1952.

Variations in displaced absorption (especially He I, Fe II etc.) have been considered by the writer as possibly due to variations in observing conditions.

These displaced absorptions are prominent in the bright inner halo and hence might be enhanced in conditions of poor seeing and guiding. The rotation of the field at the Radcliffe coudé focus would bring different portions of the halo on to the slit compared with cassegrain observations. However, the behaviour in 1965 of [Ne III] and He I emission was too extreme to be explained in this way. Moreover, the coudé spectra of 1961–1965 have shown Ti II absorption clearly stronger than on Gaviola's earlier spectra. Ti II absorption is in fact very marked relative to its emission as has been noted in many other objects, e.g. S Dor (Thackeray 1964).

Emission lines appearing double with separation of order 2 Å have been known since the early Lick observations. This phenomenon may be associated with the duplicity of the nucleus noted by double star observers or with complex conditions of the halo. It is not the purpose of the present paper to discuss this aspect of the problem of η Carinae.

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Addendum. During the writing of this paper and after completion of all the identification work, the writer received a preprint of a paper by L. H. Aller & Th. Dunham Jr, *The Spectrum of η Carinae in 1961.* This contains identifications in the region 3455–5018 Å based on Mt Stromlo coudé spectra. The agreement in general is good and the writer agrees, in particular, with Aller & Dunham's conclusion that the displaced emission components were weaker in 1960–65 than in 1953. He finds less evidence for transitions of ions (in the Fe group of elements) involving upper states with E.P. greater than 7 V, but the identifications suggested in Table II have been left unaltered since receipt of Aller & Dunham's manuscript.

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