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New Identifications of YO and CeO in R Cygni†

P. S. MURTY *Indian Institute of Astrophysics, Kodaikanal 624 103, India*

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New molecular features due to YO and CeO are reported present in the spectrum of pure S star R Cyg near minimum light. Of the nearly 60 unidentified features listed in the 4620–6420 Å region, 10 with YO and 11 with CeO are identified. Bands of the $\Delta v = 0, \pm 1$, and -2 sequences of the blue-green system (B–X) of YO are identified for the first time in stellar spectra.

The near-infrared and visible spectra of S stars are known to present numerous unidentified absorption features besides a rich variety of molecular bands due to oxides of heavy metals. The 4 Kennan (1950, 1957) bands in the 8200–9000 Å interval have been an enigma for over the past quarter century. In addition, Wing (1972) reported 5 more unidentified features in the 9200–10550 Å region. Of these total of 9 bands, only one at 9900 Å (Wing and Ford 1969) has been definitively identified as due to the FeH molecule (Nordh, Lindgren and Wing 1977; Wing, Cohen and Brault 1977; Clegg and Lambert 1978). Of the several unidentified features in the visible region of the S star spectra (Bidelman and Stephenson 1957; Wyckoff and Wehinger 1976), some have recently been identified with the CeO and ZrO molecules (Wyckoff and Wehinger 1977; Wyckoff and Clegg 1978); nevertheless, well over 80 features still remain unidentified as seen from the catalogue of band heads in R Cyg by Wyckoff and Clegg. Moreover very recently we presented an additional list of more than 20 unidentified features measured in the visible spectrum of S star π^1 Gru (Murty 1982b).

We address in this communication the problem of identification of the visible bands following on the most recent experimental results on YO and CeO molecules. Of the nearly 60 unidentified absorption features in the 4620–6420 Å region of the spectrum of R Cyg, we identify 9 with the blue-green system, 1 with the orange system of YO, and 11 with CeO. These identifications are based on the criterion of wavelength agreements of the band heads, taking into account their relative intensities. The identification details are presented in Table I. Features listed as unidentified in R Cyg by Wyckoff and Clegg are entered in column (1), followed by column (2) in which, the laboratory wavelengths are set out. In columns (3), (4), and (5) are given respectively, the identified molecule, transition and band head assignment. We present below a brief discussion on the identification details of these two molecules.

(*i*) *YO*: Two band systems, the orange system ($A\,^2\pi$–$X\,^2\Sigma^+$) and the blue-green system ($B\,^2\Sigma^+$–$X\,^2\Sigma^+$), are prominent in the visible spectrum (4500–6900 Å) of YO. Although the orange bands have long been known to be conspicuous in S star spectra (see Merrill and Greenstein 1956), the blue-green bands have not yet been identified in stellar spectra. Following the recent laboratory studies of the YO molecule (Shin and Nicholls 1977; Bernard, Bacis and Luc 1979; Bernard and Gravina 1980) we attempt to investigate if any of the B–X bands correlate with the unidentified features listed in R Cyg. Evaluated Franck–Condon intensity factors for the B–X system by Shin and Nicholls and Bernard, Bacis and Luc, suggest that the (0, 0) and (1, 1) bands of the $\Delta v = 0$ sequence are the most intense bands followed by bands of the $\Delta v = \pm 1$ and ± 2 sequences. In the light of these results, we identify the 4815 and 4840 Å bands in R Cyg as the (0, 0) and (1, 1) bands respectively of the B–X system. The 5024 and 5049 Å features are respectively identified with the (0, 1) and (1, 2) bands. In addition, 4 bands of the $\Delta v = -2$ sequence in the 5245–5345 Å interval and one band of the $\Delta v = +1$ sequence at 4709 Å are identified. The unidentified feature at 6149 Å

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TABLE I
YO and CeO identifications in the 4620–6420 Å region of the spectrum of R Cyg near minimum light.

Wavelength (Å) R Cyg (1)	Wavelength (Å) Lab (2)	Molecule (3)	Transition (4)	Band head assignment v', v'' (5)
4709.6	4706.7	YO	$B\,^2\Sigma^+$–$X\,^2\Sigma^+$	3,2
4764.6	4764.8	CeO	g_2–X_2	0,0
4815.1	4817.4	YO	B–X	0,0
4840.3	4842.0	YO	B–X	1,1
4872.8	4873.8	CeO	D_3–X_3	0,0
4879.0	4879.9	CeO	D_3–X_3	0,0
4931.1	4931.8	CeO	C_1–X_1	0,0
4937.2	4937.0	CeO	C_1–X_1	1,1
5024.5	5024.3	YO	B–X	0,1
5049.0	5049.6	YO	B–X	1,2
5070.9	5070.3	CeO	D_3–X_3	0,1
5084.0	5083.5	CeO	D_3–X_3	0,1
5172.7	5172.4	CeO	C_1–X_1	2,3
5246.4	5248.1	YO	B–X	0,2
5276.5	5275.4	YO	B–X	1,3
5304.3	5304.4	YO	B–X	2,4
	5304.6	ZrO	$c\,^3\pi$–$a\,^3\Delta$	1,0
5341.7	5338.7	YO	B–X	3,5
5843.6	5843.7	CeO	e_2–X_2	0,0
6045.5	6045.8	CeO	B_1–X_1	0,0
6080.6	6080.3	CeO	E_2–X_2	0,0
6149.5	6148.4	YO	$A\,^2\pi_{1/2}$–$X\,^2\Sigma^+$	1,1

is identified as the (1, 1) band of the orange system ($A\,^2\pi_{1/2}$–$X\,^2\Sigma^+$). It may be noted from Table I that the agreement between the star and laboratory band positions is excellent for bands of the $\Delta v = -1$ sequence; however, the agreement for the remaining bands, including the intense (0, 0) and (1, 1) bands is rather poor. This could be due to the fact that the bands of the $\Delta v = +1$, 0 and −2 sequences lie in the regions of very strong ZrO α and β bands and consequently larger measuremental errors are inevitable with moderate dispersion spectra. Although the present identifications of 9 bands provide enough evidence for the blue-green bands in R Cyg, one would expect a firm confirmation when higher resolution spectra (4500–5500 Å) of pure S stars are available.

(*ii*) *CeO:* The CeO molecule has been identified in stellar spectra for the first time by Wyckoff and Wehinger (1977), who reported a tentative identification of 15 bands in the spectrum (4500–8200 Å) of R Cyg at minimum light. Subsequently Clegg and Lambert (1978) fully confirmed the presence of CeO in S stars by resolving the rotational structure of the bands. The laboratory spectrum of CeO as investigated recently by Barrow *et al.* (1979) is known to exhibit numerous bands degraded in either direction; more than 300 bands were identified in the region between 3600 and 8600 Å. Owing to the complex structure of the bands, even the vibrational analyses was not complete and many bands remain unassigned. However, it is fortunate that these investigations have very recently been backed up by Linton *et al.* (1979, 1981) using the laser induced fluorescence experiments. The results of these investigations of the CeO spectrum (4600–6100 Å) are used to assign some of the unidentified features in R Cyg. It may be seen from columns (1) and (2) of Table I that the stellar features match very well with the laboratory wavelengths. Of the total of 11 identified features, 5 are newly identified as due to the C_1–X_1 and D_3–X_3 systems, while the remaining 6, for which the identifications were doubtful, are now confirmed as due to CeO. The present identifications strongly suggest that when further laboratory results of Linton *et al.* covering the region between 6000 and 9000 Å are available, it would be possible to assign some more unidentified bands in R Cyg, including those of the recently observed CeO bands at 8560 and 8584 Å in R Cyg by Lambert and Clegg (1980) and bands in the 6040–7300 Å region of the spectrum of π^1 Gru (Murty 1982a).

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REFERENCES

Barrow, R. F., Clements, R. M., Harris, S. M. and Jenson, P. P., 1979. *Astrophys. J.*, **229**, 439.
Bernard, A., Bacis, R. and Luc, P., 1979. *Astrophys. J.*, **227**, 338.
Bernard, A. and Gravina, R., 1980. *Astrophys. J. Suppl.*, **44**, 223.
Bidelman, W. P. and Stephenson, C. B., 1957. *Mém. Soc. R. Sci. Liège*, **18**, 292.
Clegg, R. E. S. and Lambert, D. L., 1978. *Astrophys. J.*, **226**, 931.
Keenan, P. C., 1950. *Astron. J.*, **55**, 74.
Keenan, P. C., 1957. *Publ. Astron. Soc. Pac.*, **69**, 5.

Lambert, D. L. and Clegg, R. E. S., 1980. *Mon. Not. R. Astron. Soc.*, **191**, 367.
Linton, C., Dulick, M. and Field, R. W., 1979. *J. Mol. Spectrosc.*, **78**, 428.
Linton, C., Dulick, M., Field, R. W., Carette, P. and Barrow, R. F., 1981. *J. Chem. Phys.*, **74**, 189.
Merrill, P. W. and Greenstein, J. L., 1956. *Astrophys. J. Suppl.*, **2**, 225.
Murty, P. S., 1982a, to be published.
Murty, P. S., 1982b, to be published.
Nordh, H. L., Lindgren, B. and Wing, R. F., 1977. *Astron. Astrophys.*, **56**, 1.
Shin, J. B. and Nicholls, R. W., 1977. *Spectrosc. Lett.*, **10**, 923.
Wing, R. F., 1972. *Mém. Soc. R. Sci. Liège*, **3**, 123.
Wing, R. F., Cohen, J. and Brault, J. W., 1977. *Astrophys. J.*, **216**, 659.
Wing, R. F. and Ford, W. K., 1969. *Publ. Astron. Soc. Pac.*, **81**, 527.
Wyckoff, S. and Clegg, R. E. S., 1978. *Mon. Not. R. Astron. Soc.*, **184**, 127.
Wyckoff, S. and Wehinger, P. A., 1976. *Mém. Soc. R. Sci. Liège*, **9**, 445.
Wyckoff, S. and Wehinger, P. A., 1977. *Astrophys. J. Lett.*, **212**, L139.