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Intensity distribution in the $A^2\Pi - X^2\Sigma^+$ system of Yttrium monoxide

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Abstract. The integrated intensities of a few bands in the vibrational structure of the astrophysically significant 'orange' system of the molecule yttrium monoxide, have been measured experimentally by the technique of photographic photometry. The effective vibrational temperatures of the source are found to be 2402 ± 180 K and 2901 ± 230 K for the subsystems $A^2\Pi_{3/2} - X^2\Sigma^+$ and $A^2\Pi_{1/2} - X^2\Sigma^+$ respectively.

Keywords. Intensity measurements; molecular processes; yttrium monoxide.

1. Introduction

Spectroscopic investigations have revealed the existence of YO in various astrophysical sources. Band-head measurements by Davis (1947) have established the presence of YO in the star β-Pegasi which belongs to the spectral class M2. Lin (1949) has reported YO bands in the spectrum of χ-Cygni. Ten bands are said to appear readily, the strongest being those at wavelengths 4817, 5972 and 6132 Å. Merrill and Greenstein (1956) observed that abnormally strong absorption bands of YO and LaO are the features in the spectra of star Andromadae, a long period star of class S. In certain Mira variables later than M5, strengthening of YO and ScO indicates a tendency towards spectral type S. Babcock (1945) and Swings (1958) have shown that the disc-spectra of sunspots also show the bands of YO. Laboratory investigation on the spectra of YO is therefore necessary for a better understanding of the solar and stellar atmospheres. Further, the possible development of chemical laser (visible region) has stimulated detailed spectroscopic investigations of the 'orange' system of YO (Chalek and Gole 1976).

So far, only eye estimates of intensity reported by Meggers and Wheeler (1931) are available for the A-X system of YO. In the present study of the transition, integrated intensity measurements are made by the method of photographic photometry for five bands each of the $\Delta v=0$ sequences in the sub-systems, $A^2\Pi_{3/2} - X^2\Sigma^+$ and $A^2\Pi_{1/2} - X^2\Sigma^+$. Recent analysis and studies by Bernard *et al* (1979) have provided improved molecular constants, Franck-Condon (FC) factors and *r*-centroids for the system. These results are used together with the intensities measured in the present investigation to evaluate the effective vibrational temperatures of the source for the two sub-systems.

2. Experimental

The bands of YO were excited in a dc arc. Two power supply units (AIMIL, India) were used to run the arc with a flat-topped iron rod of diameter 8 mm and a brass rod of diameter 5 mm as the positive (lower) and negative (upper) electrodes respectively. Small quantities of specpure Y_2O_3 (Johnson Mathey, London) were used to form a pellet of yttrium in the running arc. It was observed that the bands were well-formed in the outer edge of the crimson red flame when the arc was run at 250 volts dc and a current of about one ampere was flowing through the circuit. A two-prism glass spectrograph (Andhra Scientific Co.,) of medium dispersion (36–44 Å/mm) was used to photograph the bands on Agfa Gevaert WPI plates. A standard lamp and a step-slit were used to obtain the calibration marks on all the plates. The standard lamp was a straight-coiled bulb and was calibrated at the National Physical Laboratory, New Delhi, for a colour temperature of 1685 K with 1.5 A current flowing through the coil. The photographic plates were processed under identical conditions taking the usual precautions of photographic photometry (Murthy and Bagare 1980).

3. Method and results

A microdensitometer (Carl-Zeiss) of pen recorder type was used to obtain the band profiles and the densities of the calibration marks at the required wavelengths. Microdensitometer traces of the bands and calibration marks in many selected plates were taken, and of these, six traces which were best suited for intensity measurements were chosen. Characteristic curves were plotted for all the six traces for the wavelengths corresponding to each of the bands studied. The band profiles were converted to intensity contours using the corresponding characteristic curves.

Extrapolation of the intensity contours was not required as the bands were distinct and well-formed. The planimetered area under the curve of each band was multiplied by the value of spectral emissivity E_λ for the wavelength of the band to obtain the integrated intensity. The intensities have been placed on a scale with the intensity of (1, 1) band as 100. The average results of six measurements are given in table 1.

All the bands of A–X system of YO studied in the present investigation belong to a single sequence, $\Delta v = 0$, and the range of the internuclear separation (r) is very small

Table 1. Relative integrated intensities for the bands of YO.

$A^2\Pi_{3/2} - X^2\Sigma^+$				$A^2\Pi_{1/2} - X^2\Sigma^+$			
v', v''	$\lambda_{v'v''}$	$I_{v'v''}$	$q^*_{v'v''}$	v', v''	$\lambda_{v'v''}$	$I_{v'v''}$	$q^*_{v'v''}$
0, 0	5972	57.5	0.996	0, 0	6132	61.4	0.996
1, 1	5988	100.0	0.987	1, 1	6148	100.0	0.986
2, 2	6004	74.2	0.975	2, 2	6165	59.4	0.972
3, 3	6020	39.1	0.962	3, 3	6182	35.5	0.956
4, 4	6037	23.3	0.946	4, 4	6200	28.7	0.935

*FC factors reported by Bernard *et al* (1979) in supplementary literature.

(0.03 Å) for these bands. Therefore the electronic transition moment R_e is assumed to be a constant in the range of $\bar{r}$ studied for the system. The measured integrated intensities are used together with the FC factors ($q^{v'\,v''}$) reported by Bernard *et al* (1979) (given in table 1) to evaluate the effective vibrational temperatures of the source as 2402 ± 180 K and 2901 ± 230 K for the $A^2\,\Pi_{3/2} - X^2\,\Sigma^+$ and $A^2\,\Pi_{1/2} - X^2\,\Sigma^+$ systems respectively (Murthy and Bagare 1980).

4. Discussion

Integrated intensities are presented for the first time for the bands of the A–X system of YO. As the system is of predominant astrophysical significance, measurements are made only for those bands whose intensities are comparable with that of the most intense band of the system. Besides the errors inherent in the technique of photographic photometry, an estimated error of 5 to 10% is involved in the measured intensities.

Under the constancy of R_e assumed for the system, the FC factors themselves represent the band strengths of the vibrational transitions. The effective vibrational temperature values obtained for the system are within the range of temperature expected in dc arc source.

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