ON THE GAMMA SYSTEM OF NITRIC OXIDE IN SUNSPOTS

(Research Note)

G. C. JOSHI, M. C. PANDE, and D. S. SHUKLA
Uttar Pradesh State Observatory, Naini Tal, 263129, India

(Received 22 May, 1978)

Abstract. With the aim of investigating the resonance system of NO, equivalent width calculations have been made for the 213.575 nm, $Q_1(31.5)$ line of the 1-0 band of γ-system of NO for the photospheric HSRA model, and for the line 214.012 nm, $Q_1(25.5)$ line of the same band system for Zwaan's (1974) sunspot model.

Calculations show that γ-band system would not show up in the photospheric spectrum whereas a sunspot model yields an equivalent width of 72 mÅ suggesting that sunspots may provide relatively more favourable conditions for the detections of the resonance systems of some abundant molecules in the inaccessible ultraviolet region.

1. Introduction

The resonance systems of some of the abundant umbral molecules fall in the UV region at wavelengths shorter than 290 nm and thus not accessible to observations made from the ground. In spite of the fact that the molecular abundances in sunspots are generally much larger than in the solar photosphere, investigations concerning predictions of molecular line strengths in the said UV region have been made only for the photospheric case. Recently the cases of the molecules H_2, CO and SiO have been considered by Krishna Swamy (1975, 1976) using the HSRA model by Gingerich *et al.* (1971). The present investigation aims to show that the γ-band system of NO, electronic transition $A^2\Sigma^+ - X^2\Pi_{1/2}$, practically undetectable in the photospheric spectrum, would probably be considerably enhanced in the umbral spectrum.

2. Equivalent Width Calculations

The method adopted for equivalent width calculations is the weak line approach as used by Waddell (1958). The models selected for the calculations are the HSRA photospheric model and the Zwaan's (1974) sunspot model, hereinafter called ZSM-74. The ZSM-74 model was selected for these calculations since this model is more refined than the earlier continuum based sunspot models (cf., Zwaan, 1974). HSRA abundances have been adopted except for nitrogen for which the abundance quoted by Boyer and Sotirovski (1973) has been used along with a H to He ratio of 10:1. For the continuous opacity calculations the absorption cross-sections for AlI, MgI, and SiI by Travis and Matsushima (1968) and the absorption cross-section for H^- and scattering due to H, H_2 and electrons by Tsuji (1964) were used.

Solar Physics **58** (1978) 343–346.

For the photospheric case the 213.575 nm, $Q_1(31.5)$ line of the 1—0 band of γ-system of NO was selected for equivalent width calculations for the following reasons. At this wavelength the contributions to the continuous opacity by the molecules CO and SiO are expected to be inappreciable (cf., Krishna Swamy, 1976). An inspection of Franck-Condon factors by McCallum *et al.* (1972) suggests that the 1-0 band would be the strongest band. Further, under photospheric conditions, the population of the rotational levels is expected to peak around the rotational quantum number $J = 31.5$ for which the rotational line strength factors S_J from Schadee (1964) show the largest values for the Q_1 branch. Molecular constants from Carpenter and Franzosa (1965) along with a band oscillator strength of 8.09×10^{-4} given by Farmer *et al.* (1972) were used. An equivalent width of 0.4 mÅ is obtained for the HSRA photospheric model at the centre of the disc when along with the other sources enumerated above the additional source of opacity suggested by Matsushima (1968) is also included. However, the equivalent width calculated by us without the additional source of opacity again turns out to be small (<1 mÅ) for detection in the photospheric spectrum.

Under sunspot conditions, the population of the rotational levels is expected to peak around $J = 26.5$. The 214.012 nm, $Q_1(25.5)$ line of the 1-0 band of the γ-system of NO was selected for equivalent width calculations to avoid contaminations by the molecules CO and SiO. The contributions by the latter molecules are expected to become inappreciable at this wavelength as per predictions for the photospheric case by Krishna Swamy (1976) and opacity considerations by Tarafdar and Vardya (1972). Other abundant molecules such as H_2, N_2, CH, CN, MgH, TiO, NH, OH, SiH and H_2O are not expected to contaminate the predicted equivalent widths since their resonance systems fall elsewhere. An equivalent width

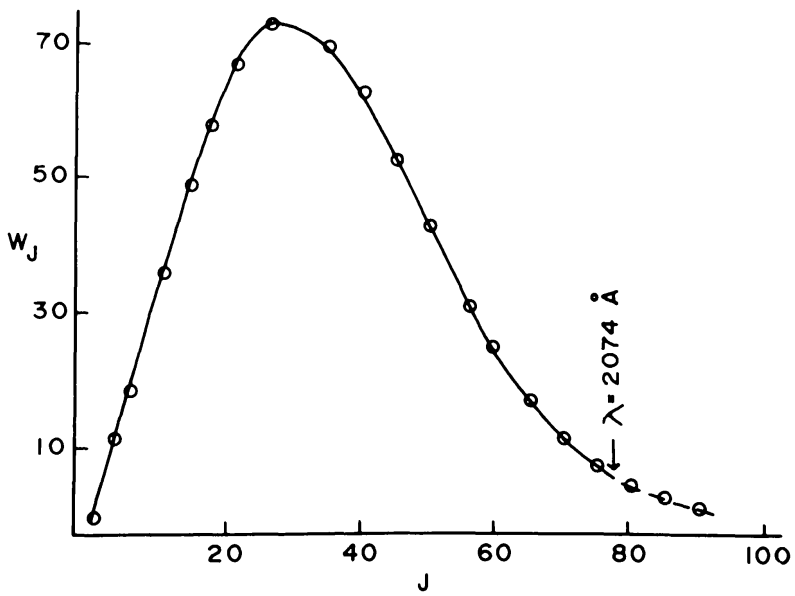

Fig. 1. Dependence of equivalent width W_J(mÅ) on the rotational quantum number J of the lower level for the lines of the Q_1 branch of the 1-0 band of γ-system of NO in the sunspot model ZSM-74.

of 72.0 mÅ results for the selected line of the γ-band of NO in ZSM-74 at the centre of the disk. From the contribution function of this line the average depth of formation is established to be $\tau(500\,\text{nm}) = 0.178$ where the temperature is $T = 3552$ K. At this temperature in the weak line approximation the equivalent widths of the lines of the Q_1 branch of the 1-0 band of the γ-system of NO are expected to manifest a variation approximately as shown in Figure 1.

3. Discussions

Before establishing the presence of NO γ-system in the sunspot spectrum, the following points need further consideration:

(i) The spectrum of NO considered by us runs from 214.8 nm ($J'' = 0.5$) to 207.4 nm ($J'' = 70$). In this wavelength region we calculated the opacity due to molecules CO(A—X) and SiO(A—X). The opacity due to these molecules is less than 10^{-3} cm^2 g^{-1} at all tabulated depths in the model ZSM-74.

(ii) The opacity due to Aluminium starts becoming important (>10 cm^2 g^{-1}) at 207.4 nm and shorter wavelengths. Therefore, we have restricted the W_J versus J plot up to only 207.4 nm marked by an arrow in the figure.

(iii) The value of oscillator strength used by us is from the investigation carried out by Farmer *et al.* (1972) and this value is in good agreement with the values determined earlier by various authors.

(iv) The value of the dissociation potential of NO used by us is 6.51 eV, whereas JANAF Thermochemical Tables (Stull *et al.*, 1970) give a value of 6.48 eV. The latter value reduces the expected equivalent widths by a factor of 0.90 only.

Among the various electronic transitions originating from the ground electronic state namely β, γ, δ, and ε bands, the γ-band only has been investigated by us here. The δ and ε bands were not investigated by us since these bands fall in the region 184.0 nm to 210.0 nm and 170.0 nm to 190.0 nm respectively. Our calculations of metallic continuous opacity in this wavelength region show that the opacity gets considerably enhanced in the upper photospheric layers of the umbra and consequently absorption lines of these systems will not be visible. For β-bands an inspection of the Franck-Condon factors suggests that the bands originating from higher vibrational levels (v'') should be most intense.

4. Conclusion

Thus the γ-band system of NO will not show up in the photospheric spectrum since even without the unknown opacity source of Matsushima (1968) the equivalent widths of the 1—0 band of this system turn out to be inappreciable. However, this band of the γ-system gets considerably strengthened in sunspots and may show up in their spectra. This also suggests that sunspots may provide relatively more favourable conditions for the detection of the resonance systems of some abundant molecules in the inaccessible ultraviolet region.

Acknowledgement

Thanks are due to V. P. Gaur for useful discussions.

References

Boyer, R. and Sotirovski, P.: 1973, *Astron. Astrophys.* **28**, 151.
Carpenter, R. O'B. and Franzosa, M. A.: 1965, *J. Quant. Spectros. Radiat. Transfer* **5**, 465.
Farmer, Q. J. D., Hasson, V., and Nicholls, R. W.: 1972, *J. Quant. Spectros. Radiat. Transfer* **12**, 627.
Gingerich, O., Noyes, R. W., Kalkofen, W., and Cuny, Y.: 1971, *Solar Phys.* **18**, 347.
Krishna Swamy, K. S.: 1975, *Solar Phys.* **41**, 301.
Krishna Swamy, K. S.: 1976, *Solar Phys.* **47**, 469.
McCallum, J. C., Jarmain, W. R., and Nicholls, R. W.: 1972, *Spectroscopic Report No. 4*, CRESS, York University, Canada.
Matsushima, S.: 1968, *Astrophys. J.* **154**, 715.
Schadee, A.: 1964, *Bull. Astron. Inst. Neth.* **17**, 311.
Stull, D. R., Prophet, H., Chao, J., Hu, A. T., Phillips, E. W., Karris, G. C., Wollert, S. K., Levine, S., Curnutt, J. L., Rizos, J. A., Justice, B. H., Oetting, F. L., Syverud, A. N., Devgazarian, T. E., Swanson, A. C., Webb, D. U., DuPlessis, L. A., Unger, H. K., Orehotsky, R. S., Petrella, R. V., Hadden, S. T., and Sinke, G. C.: 1970, *JANAF Thermochemical Tables*, 2nd edition, National Standard Reference Data Series–National Bureau of Standards 37.
Tarafdar, S. P. and Vardya, M. S.: 1972, *Astrophys. J.* **171**, 185.
Travis, L. D. and Matsushima, S.: 1968, *Astrophys. J.* **154**, 689.
Tsuji, T.: 1964, *Publ. Astron. Soc. Japan* **18**, 127.
Waddell, H. J.: 1958, *Astrophys. J.* **127**, 284.
Zwaan, C.: 1974, *Solar Phys.* **37**, 99.