Table II

J	The whole Sun				Northern hemisphere				Southern hemisphere			
	f'	τ'	f_0	T_0	f'	τ'	f_0	T_0	f'	τ'	f_0	T_0
1962	152	431	346·0	7·38	100	296	211·6	8·28	52	135	134·4	5·95
1963	119	330	280·4	6·97	89	254	200·5	7·50	30	76	79·9	5·63
1964	60	150	162·4	5·47	39	105	95·9	6·48	21	45	66·5	4·01

for the northern hemisphere of the Sun,

$$\Sigma f_0 = 3799$$
$$\overline{T}_0 = 9{\cdot}97$$

and for the southern hemisphere of the Sun,

$$\sum f_o = 2857$$
$$\overline{T}_0 = 9{\cdot}64\,.$$

This definite Σf_0 and $\overline{T}_0$ values do not change the conclusion, obtained in the previous paper (Kopecký, 1972), that the very high value of the Wolf number in cycle No 19 is a product of superimposing the 80-year period of the mean spot group lifetime and the very long secular variation of the number of newly formed spot groups.

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REFERENCES

Chapman, S., Bartels, J.: 1940, Geomagnetism (Oxford).
Kopecký, M.: 1958, Publ. Astron. Inst. Czechosl. Acad. Sci. No 42.
—: 1960, Bull. Astron. Inst. Czech. **11**, 35.
—: 1967, Adv. Astron. Astrophys. **5**, 189.
—: 1972, Bull. Astron. Inst. Czech. **23**, 55.
Kopecký, M., Suda, J.: 1965, Bull. Astron. Inst. Czech. **16**, 78.

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VIBRATION-ROTATION BANDS OF HF, HBr AND HI IN THE SUNSPOT SPECTRUM

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The calculated equivalent widths of $R(7)$, $R(9)$ and $R(13)$ lines of 1—2 vibration-rotation band of HF for Henoux's (1969) sunspot model suggest the presence of this band in sunspot spectrum. The reasons for the absence of the vibration-rotation bands of HBr and HI in the sunspot spectrum are discussed.

Вибрационно-ротационные полосы HF, HBr и HI в спектре солнечных пятен

Вычисленные эквивалентные ширины линий $R(7)$, $R(9)$ и $R(13)$ 1—2 вибрационно-ротационной полосы HF для модели солнечного пятна Хеноукса (1969) наводят мысль о присутствии этой полосы в спектре солнечного пятна. Обсуждается причина отсутствия вибрационно-ротационных полос HBr и HI в спектре солнечного пятна.

1. Introduction

The identification of some lines of 0—1 band of HF by Hall and Noyes (1969) and the fact that the oscillator strength associated with the 1—2 band of HF is twice that of 0—1 band (cf. equation 7—95 of Penner, 1959) suggest that 1—2 and other bands of HF may also show up in the sunspot spectrum. The aim of the present communication is to predict the equivalent widths of some strong lines of the 1—2 band of HF for Henoux's (1969) sunspot model and to suggest the desirability of its identification in the sunspot spectrum.

As the vibration-rotation bands of HCl have also been detected in the sunspot spectrum (Hall and Noyes, 1972) it may be pertinent to discuss here the cases of the vibration-rotation bands of HBr and HI in the sunspot spectrum.

2. Equivalent Width Calculations of HF Lines

The equivalent widths of the $R(7)$, $R(9)$ and $R(13)$ lines of the $1-2$ band and $R(7)$ line of the $0-1$ band of HF were calculated for Henoux's (1969) sunspot model (effective temperature = 3 650 K) at the center of the disk. These lines were selected because in sunspot the population of HF molecules will peak around $J = 7$ to 9. The abundance of F was taken as 4·56 (Hall and Noyes, 1969) on the scale $\log H = 12$.

The wavelengths of $R(7)$, $R(9)$ and $R(13)$ lines of $1-2$ band were calculated with the help of the molecular constants of Herget et al. (1962) and are respectively 2.471046, 2·441497 and 2·397581 microns. The oscillator strengths, $f_{\text{vib}} . S_J/(2J + 1)$, for the $1-2$ band rotational lines, were calculated from the integrated absorption cross section α for the fundamental band in units of cm^2 per molecule in the lower state of the transition, quoted in Hall and Noyes (1969). The formulation used is:

$$f = f_{\text{vib}} . S_J/(2J + 1) = 2 . (mc^2/\pi e^2) . \alpha .$$

The factor 2 is the ratio of the squares of the vibrational matrix elements for the $1-2$ and $0-1$ bands of HF (Penner, 1959). The resulting oscillator strengths for $R(7)$, $R(9)$ and $R(13)$ lines are $12{\cdot}04 \times 10^{-6}$, $9{\cdot}92 \times 10^{-6}$ and $8{\cdot}14 \times 10^{-6}$ respectively. Other quantities needed for equivalent width calculations were obtained as earlier (Gaur et al., 1971; Gaur and Pande, 1972).

For the center of the disk equivalent widths of the $R(7)$, $R(9)$ and $R(13)$ lines of $1-2$ band are 137·1, 104·8 and 61·6 mA respectively.

3. Vibration—Rotation Bands of HBr and HI

The abundances of HCl, HF, HBr and HI calculated by us for Zwaan's (1965) sunspot model show that both HBr and HI are many orders of magnitude less abundant in sunspots than HCl and HF. Of course, we assumed solar system abundances for Br and I which may be justified as the solar abundances of Cl and F are not too far off from the solar system abundances. The integrated absorption coefficients for the fundamental bands of HBr and HCl are 55 and 150 $\text{cm}^{-2}\ \text{atm}^{-1}$ (Penner, 1959). These lead to the vibrational oscillator strengths of $2{\cdot}2 \times 10^{-6}$ and $6{\cdot}0 \times 10^{-6}$ respectively. Thus the oscillator strengths are comparable but the disparity in the abundance of HBr and HCl suggest that the various vibration-rotation bands of HBr, namely $0-1$, $1-2$, $2-3$, $3-4$ and overtones, will not be observable in the infrared sunspot spectrum (cf. Table $7-1$ of Penner, 1959). As HI is less abundant than HBr by three orders of magnitude in sunspots, it cannot show vibration-rotation bands in the spectrum.

4. Concluding Remarks

In brief, we conclude from the above that the $1-2$ and other bands of HF may show up in the sunspot spectrum. However, to check our results the equivalent width of $R(7)$ line of $0-1$ band of HF was also obtained for Henoux's (1969) model at $\cos \Theta = 1$. The resulting value of 187·25 mA agrees fairly well with the extrapolated theoretical value given by Hall and Noyes (1969) for a model having the same effective temperature as that of Henoux's (1969) model. The observed equivalent width for this line in a large round sunspot (effective temperature = 4000 ± 200 K) at $\cos \Theta = 0{\cdot}65$ is 41 ± 6 mA. Obviously, our calculated value is larger by a factor 4 to 5 because Henoux's (1969) model is cooler. However, even if our predicted equivalent widths of $R(7)$, $R(9)$ and $R(13)$ lines of $1-2$ band of HF are reduced by such a factor these lines remain detectible. Further, an inspection of the formula $7-95$ of Penner (1959) suggests that the $2-3$ and $3-4$ bands of HF may also be present while its overtones such as $0-2$ may not show up in the sunspot spectrum. Summing up, we suggest that the vibration-rotation bands $1-2$, $2-3$, and $3-4$ of HF be searched in the sunspot spectrum.

Very small abundances of HBr and HI in sunspots show that their vibration-rotation bands will not show up in the sunspot spectrum even though the oscillator strengths are comparable with the bands of HCl and HF.

REFERENCES

Gaur, V. P., Pande, M. C., Tripathi, B. M. Joshi, G. C.: 1971; Bull. Astron. Inst. Czech. **22**, 157.

Gaur, V. P., Pande, M. C.: 1972; Symp. on Spectrosc. Studies of Astrophys. Interest (C.A.S. in Astron., Osmania University, Hyderabad, India), to be publ.

Hall, D. N. B., Noyes, R. W.: 1969; Astrophys. Letters **4**, 143.

—: 1972; Astrophys. J. (Letters) **171**, L95.

Henoux, J. C.: 1969; Astron. Astrophys. **2**, 288.

Herget, W. F., Deeds, W. F., Gallar, N. M., Lovell, R. J., Nielson, A. H.: 1962; J. Opt. Soc. Amer. **52**, 1113.

Penner, S. S.: 1959, Quantitative Molecular Spectroscopy and Gas Emissivities (Pergamon Press Ltd., London, Paris).

Zwaan, C.: 1965; Recherches Astron. Obs. Utrecht XVII(4), 177.

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