Centre to Limb Variation of Rotational Temperature of the CH Molecules in the Solar Photosphere

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Abstract

Spectrophotoelectric observations of the CH lines have been presented to determine the centre-to-limb behaviour of rotational temperatures for the (0—0) and (1—1) bands of the electronic transition $A^2\triangle - X^2\Pi$ of the molecule. Taking into account the large probable errors in measurements, we find that the rotational temperature from centre to limb appears practically constant. Further accurate observations upto the exteme limb with a larger set of data appear necessary in order to minimise the probable errors.

INTRODUCTION

Sufficient evidence for the absence of deviations from LTE in the populations of vibrational and rotational levels of molecules in the solar photosphere has accumulated in recent years (Pande 1967; Sarychev, 1971; Thomson 1973; Hinkle and Lambert 1975). Consequently, at each depth in the photosphere the vibrational and rotational levels of molecules should be populated according to the local kinetic temperature. This circumstance is significant since it allows the use of rotational temperatures, T(*rot*), for refining photospheric models (cf. Khlistov 1972; Sinha et al. 1979). Further, in case a certain molecule shows two or more vibrational systems belongning to the same electronic transition then the *C-L* (centre-to-limb) variations of T(*rot*) for the two cases may provide a better coverage in optical depth. However, investigations based on observational determination of the *C-L* variations of rotational temperatures are still scanty (e.g., see Polonskij, 1968).

In view of the above, spectrophotoelectric observations aimed at determining the *C-L* variations of T(*rot*) for the (0-0) and (1-1) bands of the electronic transition $A^2\triangle$ -$X^2\Pi$ of the CH molecule in the photospheric specturm were initiated in 1974.

The present communication reports the results of this inivestigation.

INSTRUMENTATION

(a) **Horizontal-solar telescope and single pass spectrograph:**

A detailed description of the solar horizontal telescope and its associated single pass spectrograph used for the observations has been given earlier (Pande 1975). Briefly, a 25-cm aperture, f/66 off-axis horizontal solar telescope forms a 16-cm image of the Sun on the slit of the spectrograph. Two 25-cm aperture, 9 metre focal length concave mirrors and a Bausch and Lomb grating, with 600 lines / mm ruled over an area 102 mm x 203 mm and blazed at 2.5 μm in the first order, are used in a Czerny-Turner type configuration in the associated single pass spectrograph. The observations were carried out in the fifth order of the spectrum at a dispersion of 0.24 Å/mm. Necessary cutoff filters were employed to exclude overlapping orders.

b) **Recording system :** The grating rotation mode provided in the spectrograph was utilised for photoelectric registration of the spectrum with the help of a 1P21 photomultiplier, thermoelectrically cooled to -20°C and placed at the exit slit of the spectrograph. The output from the photomultiplier, after amplification with the help of a conventional d.c. amplifier in the earlier phase of observations and an operational electrometer type of d.c. amplifier in the later phase, was fed to a Hewlett-Packard strip chart recorder. The spectrum was scanned past the photometer slit at 0.60Å/sec.

OBSERVATIONS and RESULTS

The photospheric spectrum in the wavelength region λ 4180-4400Å was scanned photoelectrically for *C-L* positions $\cos\theta$=1, 0.83, 0.49 and 0.35. Each selected line of the (0-0) and (1-1) bands of the electronic transition $A^2\triangle - X^2\Pi$ of the CH molecule was scanned 5 to 10 times. After selection of fairly good lines (listed in Table 1) and a careful location of the continuum in the vicinity of the investigated lines, equivalent widths were obtained by planimetring the tracings. The equivalent width obtained from individual scans show a scatter in equivalent width values of about

TABLE 1

Equivalent widths of the lines of (0-0) and (1-1) bands of the $A^2\Delta$ —$X^2\Pi$ transition of CH molecules.

Branch	N	Wavelength (Å)	log S_N	EQUIVALENT WIDTH IN mÅ			
				$\cos\theta$ =1	$\cos\theta$ =0.83	$\cos\theta$ =0.49	$\cos\theta$ =0.35
(0-0) band							
R$_{2cd}$	7	4267.389	0.12	64.5	70.7	79.2	79.5
R$_{1cd}$	9	4255.251	0.24	61.3	63.7	68.2	67.4
R$_{1cd}$	10	4248.944	0.27	66.9	65.0	68.7	69.2
R$_{1dc}$ + R$_{2dc}$	15	4218.725	0.68	82.4	82.2	84.8	84.7
R$_{2cd}$ + R$_{1cd}$	16	4210.967	0.70	96.3	96.5	105.4	106.5
R$_{2cd}$	19	4192.572	0.76	65.9	72.8	76.4	70.8
Q$_{1d}$ + Q$_{2d}$	19	4288.736	0.99	84.0	87.9	86.1	89.4
Q$_{1d}$ + Q$_{2d}$	22	4281.972	1.05	84.0	82.7	85.4	86.3
(1-1) band							
R$_{2cd}$ + R$_{2dc}$	2	4296.217	0.13	41.8	47.2	57.2	56.5
P$_{2dc}$	4	4332.169	—0.79	6.5	7.4	9.3	9.7
R$_{1cd}$	11	4247.726	0.30	40.4	43.8	47.0	50.7
P$_{1dc}$ + P$_{2dc}$	15	4378.913	0.48	46.7	53.0	53.0	52.9
R$_{1cd}$ + R$_{2cd}$	17	4216.599	0.72	49.6	51.4	59.4	60.7
R$_{1cd}$ + R$_{2cd}$	19	4107.408	0.76	55.1	63.5	65.0	69.1

5 and 15 percent for moderately strong and weak lines respectively. The mean equivalent widths are given in Table 1. A comparison of the equivalent widths measured by various investigators, shows that the different measurements manifest differences in equivalent widths upto 15 percent (cf. Withbroe 1968 ; Baschek and Holweger 1967). The actual deviation in equivalent widths for any given line depends on such factors as the purity of the line, uncertainty in the location of the local continuum, the strength of the line and instrumental errors. The observed equivalent widths (cf. Table 1) were used to deteimine the rotational temperatures for the (0-0) and the (1-1) bands of the $A^2\Delta$ —$X^2\Pi$ transition of the CH molecule for four cos θ positions employing the relationship:

$$\log(W_N/S_N)= \text{constant} - 0.6246\, Bv''N(N+1)/T(rot) \quad (1)$$

where W_N is the equivalent width of a line originating from the lower electronic level with vibrational and rotational quantum numbers v'' and N respectively.

S_N is the rotational line strength for the line originating from the quantum number N. Bv'' is the rotational constant for the vibrational state v'' of the lower eleectronic state involved in the transition. The molecular constants have been taken from Glushko et al. (1962). The determination of the Hönl-London factors has been done from Table 3 of Schadee (1964) considering the transition to be Hund's case b (Baschek and Holweger 1967). The resulting rotational temperatures were obtained through a least-square fit between the quantities log (W_N/S_N) and Bv'' $N(N+1)$ and are tabulated in Table 2. Incase of the (1—1) band, the lines are weak as compared with the lines of the (0-0) band, and consequently the errors in rotational temperatures turn out to be larger. For the (0-0)band at $\cos\theta$=1, Ruzickova-Topolova (1965) obtained $T(rot)$ = 5140±660 K while the equivalent width data by Withbroe (1967) for the same lines, as used by us, yields $T(rot)$ = 5000 ± 470 K. Thus the rotational

temperatures obtained by us are within the errors of these determinations. Comparison with earlier determinations of T (rot) such as by Richardson (1931), Hunaerts (1947) and Laborde (1961) is not appropriate since better formulations for Hönl-London factors have now become available (cf. Schadee 1964).

TABLE 2

Rotational temperatures of the (0-0) and (1-1) bands of CH versus $\cos \theta$ values

$\cos \theta$	Rotational Temperatures	
	(0-0) band	(1-1) band
1.00	4790 ± 400 K	5200 ± 650 K
0.83	4760 ± 410 K	5130 ± 780 K
0.49	4580 ± 460 K	4940 ± 480 K
0.35	4580 ± 430 K	4830 ± 660 K

DISCUSSIONS

Table 2 gives the rotational temperatures for both the (0-0) band and the (1-1) band of the $A^2 \triangle - X^2 \Pi$ transition of the CH molecules for various $\cos \theta$ values.

As the line forming region is shifted towards the higher and cooler regions of the solar atmosphere, a decrease of 100 K in T(rot) values towards the solar limb has theoretically been predicted (cf. Khlistov 1972). However, in view of the large probable errors in measurements (cf. Table 2), we do not compare our results with those of Khlistov (1972). The temperature from centre to limb appears practically constant. Further accurate observations upto the extreme limb with a larger set of data appear necessary in order to reduce the probable errors in T(rot) determinations (cf. Sinha, 1979). Only then we feel, it would be possible to determine the true nature of the T(rot) versus $\cos \theta$ curve for the photospheric CH molecules.

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