CENTRE TO LIMB BEHAVIOUR OF MOLECULAR ROTATIONAL TEMPERATURES

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Abstract

Withbroe's (1968) photospheric data on the equivalent widths of C_2 lines for various positions on the solar disc have been utilized by us to determine the centre to limb behaviour of the rotational temperature. In view of current efforts aimed at improvements in standard photospheric models, the present day limitations in observational data on molecular lines and their analysis are discussed here.

1. INTRODUCTION

Investigations carried out by Webber (1971), Sinha (1977) and Tsuji (1977) indicate that the calculation of a model based excitation temperature for molecular lines might be helpful in picking up representative photospheric and umbral model atmospheres. The two main assumptions involved in these investigations have been that (i) the lines of a molecular band originate from a thin isothermal layer of the atmosphere and (ii) the line formation is through pure absorption. Schadee (1964) has demonstrated that the hypothesis of thin layer formation is valid and also that the molecular rotational temperature, written as T(rot), can be equated to the model temperature at the depth of line formation defined through the contribution function calculations.

Recently, Hinkle and Lambert (1975) have found evidence for line formation through non-LTE mechanisms near the solar limb. In their analysis for the MgH and C_2 lines it is concluded that though for the centre of the solar disc there is no difference in the use of the assumption of LTE and that of non-LTE, the inclusion of non-LTE effects in line formation is needed to explain the centre to limb (hereinafter abbreviated as C-L) behaviour of equivalent widths. Also the theoretical model based temperatures of line formation calculated on the assumption of LTE and that of non-LTE for the molecule CN are not found to be the same at near limb positions (Mount and Linsky 1974a, 1975). So, an investigation regarding the C-L behaviour of molecular rotational temperatures is important from two viewpoints, viz. (i) to select a representative model atmosphere and (ii) to assess the extent to which non-LTE mechanisms of line formation are operative near the limb.

Prior to a theoretical model based effort for T(rot) determination at various positions on the solar disc, one would need similar results through observations. Here we present the results of T(rot) calculations utilising Withbroe's (1968) observations for the C_2 molecules.

2. FORMULATIONS AND CALCULATIONS

The molecular rotational temperature is derived from the following equations :

$$\log (W_J/S_J) = \text{Constant} - 0.62473 \times B_{V''} J\,(J+1)/T(\text{rot}) \qquad 2.1$$

where W_J and S_J are the equivalent widths and the rotational line strengths respectively for the line originating from the quantum number J. $B_{V''}$ is the rotational constant for the vibrational state v" of the lower electronic state involved in the transition.

3. RESULTS AND DISCUSSIONS

The line identifications for the C_2 molecules were obtained by comparing the wavelengths utilized by Withbroe (1968) with those given by Phillips and Davis (1970). This comparison enabled us to conclude that a number of lines utilized in the investigation are coincident with other C_2 lines having a different rotational quantum number J. In such cases the usual log (W_J/S_J) versus J (J + 1) plot is not of use for T(rot) determinations. However most of the contaminated lines referred tc above originate from the same K leveg Therefore, if there are three lines a, b and c, originatinl. from the same K level of a vibrational state, one can write,

$$W_{K(a,b,c)} \propto S_{K(a,b,c)} \exp\,[\,-K(K+1)\,] \times B_{V''}\, hc/kT(\text{rot}), \qquad 2.2$$

so that

$$\log\,(\Sigma W_K/\Sigma S_K) = \text{Constant} - 0.62473 \times B_{V''}\, K(K+1)/T(\text{rot}). \qquad 2.3$$

The rotational line strengths are obtained from Schadee (1964).

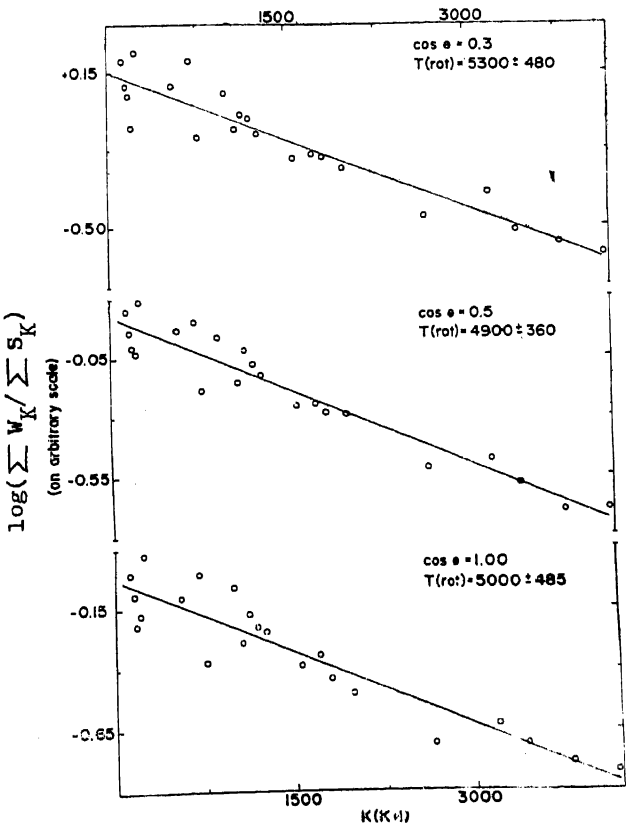

Fig. 1 : C-L behaviour of the rotational temperature of the photospheric C_2 molecules.

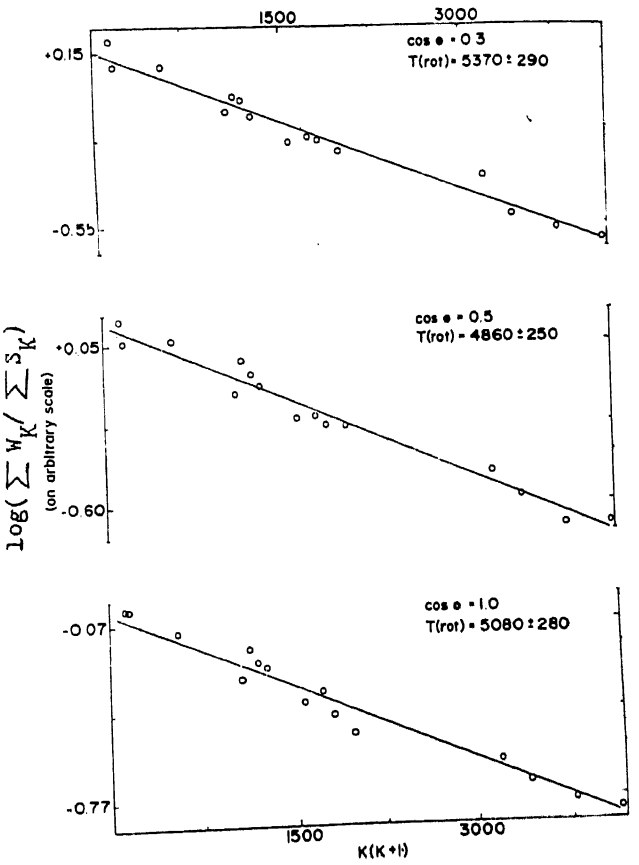

Fig. 2 : Same as in Figure 1. A few lines used in Figure 1 for T(rot) determinations are not included here (cf. text).

The results are presented in Figure 1 which shows large scatter of points around the straight line obtained through the method of least squares. The scatter tends to increase the probable error in a T(rot) determination. Such large probable errors, however, can not help to know the C-L behaviour of T(rot) as the theoretically expected difference in the T(rot) values at the centre of the solar disc and the solar limb is small i.e., 100 to 300 K (Khlistov 1972 ; Mount and Linsky 1974a, 1974b, 1975). To reduce the scatter and the consequent probable error in the T(rot) determinations, we compared Withbroe's (1968) observations for the centre of the solar disc with those of Schadee (1964). The lines at wavelengths 5098.133, 5109.294, 5111.833, 5120.617, 5120.702, 5136.256, 5138.094 and 5140.363 Å have quite different equivalent widths in the two investigations. So they were dropped in a second attempt of T(rot) determination in which only the lines given in Table 1 are used. The results are presented in Figure 2.

It can be noted from Figure 2 that (i) the rotational temperature for the centre of the solar disc is 5080±250 K and (ii) after reaching a low value of 4860±250 K at cos θ = 0.5, the rotational temperature quickly rises to attain a value 5370±290 K at cos θ = 0.3.

The result 5080±250 K is somewhat higher than 4650 K, 4620 K and 4450±304 K due to Schadee (1964, 1968), Lambert (1968) and Persi (1975) respectively. This difference is mainly due to a larger set of data used by these authors. Also, Persi's (1975) investiagations are based upon an improved method, which is better than the earlier less sophisticated methods for deblending of a line. The cause for the rise in temperature in near limb position is not clear. A monotonic decrease in T(rot) values towards the limb is expected (Khlistov 1972) , because in such a case the line forming region is shifted towards higher and cooler regions of the solar atmosphere.

The possibility of the isotopic lines of the molecule MgH being coincident with the C_2 lines (Sotirovski 1971) used in the present investigation was checked with the help of the wavelengths given by Branch (1969, 1970) and Sotirovski (1972) for the molecules $Mg^{25}H^1$ and $Mg^{26}H^1$. Elimination of C_2 lines contaminated in this way has, however, little or practically no effect upon the conclusions of this investigation. This is so because (i) the isotopic abundance of Mg is small (Boyer et al. 1971) and (ii) the MgH lines themselves are weak as compared to the C_2 lines in the photospheric spectrum (Schadee 1964).

The cause of the discrepancies in the results enumerated above might lie in the technique of rotational temperature calculations also. In the present method, which is generally utilized by various investigators, all the molecular lines are used with equal weight regardless of iheir being situated in a good or in a relatively

Table 1

Lines of the C_2 molecule used for T(rot) determination in Figure 2.

Wave-Length (Å)	Line identification	Equivalent width (mÅ)		
		$\cos\theta$ =1.0	$\cos\theta$ =0.5	$\cos\theta$ =0.3
5063.177 5063.301	$R_1(42)+R_2(42)$ $R_3(42)$	15.44	22.26	26.55
5066.732 5066.863	$R_1(41)+R_2(41)$ $R_3(41)$	18.97	23.96	27.07
5073.458 5073.578	$R_1(39)+R_2(39)$ $R_3(39)$	16.47	22.48	24.75
5084.688	$P_1(64)+P_2(64)$	6.47	8.78	10.42
5086.234	$R_1(35)$ $R_2(35)$	13.80	18.35	19.02
5089.236 5089.350	$R_1(34)+R_2(34)$ $R_3(34)$	20.78	29.57	31.94
5092.292	$R_1(33)+R_2(33)$	15.50	22.20	24.40
5094.095	$P_1(61)$ $P_2(61)+P_3(61)$	10.0	12.27	16.41
5095.194	$R_1(32)+R_2(32)$	11.40	15.75	18.30
5102.422	$P_1(58)+P_2(58)+P_3(58)$	11.23	15.28	17.70
5107.872	$P_1(56)+P_2(56)$	8.86	12.50	16.60
5119.364	$R_3(23)$	6.02	8.96	9.54
5135.561 5135.672	$P_1(44)$ $P_2(44)$ $P_3(44)$	13.80	22.75	24.65
5142.092	$R_3(12)$	3.20	4.58	4.95
5143.307	$R_1(11)$	4.35	6.06	6.77

bad region of the solar spectrum, where deblending of each line and the exact location of the continuum could be less certain. Also the total number of lines utilized in T(rot) determinations is important (Schadee 1966; Wöhl 1970; Webber 1971). Lambert's (1968) remark that different authors report different equivalent widths for one and the same C_2 line bears considerable significance, particularly when the total number of lines utilized in a T(rot) determination is not large.

Therefore, for the objectives enumerated in section 1 on introduction and keeping in view the low scatter in Figure 2, further observations of the solar spectrum with low noise tracings for a large number of unsaturated lines of different molecular species at various centre to limb distances on the solar image are desired. A careful determination of equivalent widths through judicious deblending and the location of the true continuum is very necessary to keep the probable errors to a lowest possible minimum. Also, one may have to include the effects of vibration-rotation interactions within the molecule while determining T(rot) (Tsuji 1977).

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