For example, Branch (1969) and Schadee (1970) consider that the C_2 Swan band lines are considerably weakened in the umbral spectrum, while Wöhl (1972) thinks that these lines get strengthened in spots as compared with the photosphere. If the C_2 Swan band lines get strengthened in sunspot spectrum then it is reasonable to expect that the Ballik-Ramsey 0−0 band lines will also be strengthened. This gives us an additional criterion for resolving the present controversy about C_2 in sunspots. The strongest C_2 lines belonging to the Swan and Ballik-Ramsey bands should be studied at various center-to-limb positions so as to locate the place on the disk at which spot/photosphere contrast in these lines attains maximum. Of course, very careful location of the continuum in sunspot spectra and judicious corrections for scattered photospheric light will be needed in such an investigation.

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FORMATION OF C_2 MOLECULES IN SOLAR ATMOSPHERE

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It is shown that while the triplet states of Swan bands are populated through an LTE path, the singlet states of Phillips bands are not. The problems regarding the observations of the various bands of C_2 molecules in the solar photospheric and umbral spectra are discussed in the light of this result.

Образование молекул C_2 в солнечной атмосфере

Показано, что в то время как триплетные состояния полос Свана заселяются посредством LTE, сингулентные состояния полос Филлипса не заселяются. Проблемы, касающиеся наблюдений различных полос молекул C_2 в спектрах солнечной фотосферы и пятна, обсуждаются в свете этих результатов.

1. Introduction

While considering the abundances and the excitation equilibrium of C_2 molecules in the photosphere and sunspots one encounters the following problems:

(i) The absence of Phillips bands coupled with the presence of Swan bands in the photospheric spectrum (Sinha, 1973).

(ii) The absence or presence of the uninvestigated Ballik-Ramsey bands in the photospheric and spot spectra (Pande and Sinha, 1974).

(iii) Centre-to-limb variations of profiles of C_2 Swan band lines in the photospheric and sunspot spectra. For the photospheric case, the observations and model based theoretical predictions do not match near the limb if homogeneous models and LTE are assumed (Raghavan, 1968).

(iv) Observational evidence for the absence (Branch, 1969; Schadee, 1970; Sotirovski, 1971), presence (Wöhl, 1972) or weakening (Harvey, 1972) of C_2 Swan band lines in the spectra of umbrae of spots is conflicting. Theoretical LTE calculations of the equivalent widths of C_2 Swan band lines lead to the absence of these bands in the umbral spectrum (Sotirovski, 1971; Branch, 1969).

These problems cannot be lucidly interpreted unless one clarifies whether the processes of formation and disappearance of C_2 molecules in the solar atmosphere correspond to LTE or not. With this in view, we have investigated the problem of photodissociation and radiative association of C_2 molecules in the photosphere and sunspots (cf. section 2) and have discussed the implications of the results obtained.

2. Absence of C_2 Molecules in Singlet States

The radiative association probabilities for the bands of the Swan and Phillips systems are calculated by

using the quasi-classical approach of Kramers and D'ter Haar (1946).

$$(2.1) \qquad Q_{\text{rad}} = 3 \times 10^{42} f \bar{\Theta}^2 I .$$

For the symbols used we refer to the quoted paper. The potential energy curves for calculating I are obtained by using Morse potential function (Gaydon, 1968). Spectroscopic constants for the molecule C_2 are taken from Ballik-Ramsey (1963). The oscillator strengths used are $7{\cdot}459 \times 10^{-3}$ for the Phillips band system (Sinha, 1973) and $2{\cdot}4 \times 10^{-2}$ for the Swan band system (Lyddane et al., 1941). Thus, we get:

$$(2.2) \qquad Q_{\text{rad}}(\text{Phill}) = 8{\cdot}028 \times 10^{-27}$$
$$Q_{\text{rad}}(\text{Swan}) = 1{\cdot}986 \times 10^{-18} .$$

It may be mentioned that the Q_{rad} values are practically insensitive to temperature changes in the range 5 000 K to 10 000 K and that it has a value $\sim 10^{-18}$ for all the molecules considered by Kramers and D'ter Haar (1946) and also for the C_2 Swan system So, the small value for the Phillips system is real in as much as the Phillips system also belongs to the C_2 molecule. Now, following Sitnik and Pande (1968), one can write:

$$(2.3) \qquad \beta_d = \beta_r K_{C_2}/kT,$$

where β_d and β_r are the probabilities of photodissociation and recombination respectively, K_{C_2} is the dissociation constant of C_2 (borrowed from Tatum, 1966), k is the Boltzmann constant and T the temperature. Identifying β_r as Q_{rad} and taking $T = 5\,000$ K and 4 000 K as the representative temperatures for the photosphere and the spot umbra respectively, the β_d values tabulated in table 1 were calculated for the photospheric and umbral cases.

Following Kaplan and Pikel'ner (1971), we can write:

$$(2.4) \qquad \beta_\Phi = \{4\pi^2 B(\nu_0)\, e^2 f\}/(h\nu_0 mc)\ \sec^{-1}$$

as the probability of photodissociation. Here m, e, c and h are the electronic mass, electronic charge, velocity of light and Planck's constant respectively. $B(\nu_0)$ is the Planckian at the dissociation limit frequency ν_0 and f is the oscillator strength of the electronic-vibrational level involved. The above formula can be further simplified as under:

$$(2.5) \qquad \log \beta_\Phi = [\overline{22}{\cdot}8693 + 2 \log \nu_0 + \log f] - 0{\cdot}4343(h\nu_0)/kT .$$

Assuming $h\nu_0 = 6{\cdot}2$ eV (Ballik-Ramsey, 1963) and the oscillator strengths as quoted above, the β_Φ values for the photospheric and umbral cases are tabulated in Table 1.

Thus, we are able to determine the same quantity – probability of photodissociation – by two mutually independent methods. In case of LTE the two results must agree because one of the two processes is the exact reverse of the other and further as β_d has been derived under LTE conditions. A comparison of the two results can be made from the values in the following table.

3. Discussions

The table 1 clearly shows that within the uncertainties involved in these order of magnitude calculations, β_d and β_Φ values tally for the Swan system where as there is a large discrepancy for the Phillips system in spots as well as in photosphere. So, one can say that thepopulation of the $^3\Pi_u$ state is in LTE while that of $\sum_g^+$ is in non-LTE. This conclusion explains the absence of the Phillips bands in the photospheric spectrum reported by Sinha (1973). As the Ballik-Ramsey bands also arise from the $^3\Pi_u$ state, so they may be observable in the photospheric spectrum. Elsewhere we have shown that the LTE calculations of the equivalent widths of strong lines of the 0–0 band of the Ballik-Ramsey system indicate that this band may show up in the photospheric spectrum. The C–L variations of the Swan band lines near the limb may then be explained by temperature in-

Table 1

Photodissociation Probability	Phillips Band System		Swan Band System	
	Photospheric	Umbral	Photospheric	Umbral
β_d	$1{\cdot}606 \times 10^{-6}$	$4{\cdot}967 \times 10^{-8}$	$3{\cdot}972 \times 10^{2}$	$1{\cdot}229 \times 10^{1}$
β_Φ	$2{\cdot}182 \times 10^{1}$	$4{\cdot}789 \times 10^{-1}$	$7{\cdot}020 \times 10^{1}$	$1{\cdot}541 \times 10^{0}$
β_d/β_Φ	$7{\cdot}360 \times 10^{-8}$	$1{\cdot}037 \times 10^{-7}$	$5{\cdot}658 \times 10^{0}$	$0{\cdot}798 \times 10^{0}$

homogeneties in the upper photospheric layers. This explanation has also been invoked by Kozhevnikov and Polonskij (1969) to explain the parameters of the C–L variations of the CO first overtone lines in the photospheric and facular spectra.

4. Absence of C_2 in Sunspots

As the triplet states of the C_2 molecule, particularly the $^3\Pi_u$ state, correspond to a state of LTE as far as photodissociation and radiative association processes are concerned, the LTE calculations of the equivalent widths of Swan band lines appear to be valid. Such calculations lead to practically negligible equivalent widths of these lines in the sunspot umbrae (Branch, 1969; Sotirovski, 1971), basically because the abundance of C_2 in the photosphere is about 10^4 times that found in sunspots (cf. e.g. Gaur at al., 1973; Sinha, 1973). So the absence or considerable weakening of the C_2 Swan band lines in the umbral spectrum seems reasonable and confirms the conclusions of Harvey (1972). Though Schadee (1970) and Branch (1969) also conclude observationally that the C_2 Swan band lines are absent in the umbral spectrum we feel that their w_0/s_0 values for the 0–0 band lead to observable equivalent widths for the Swan band lines. If $W_J(\max)$ is the maximum equivalent width then we have from Schadee's (1964) formulation:

$$\log W_J(\max) = \log (w_0/s_0) + \log S_J(\max) - 0{\cdot}21 .$$

Schadee (1970) obtains the w_0/s_0 values varying between $-0{\cdot}02$ to $+0{\cdot}07$ from Branch's (1969) observations for the 0–0 band. The maximum intensity of C_2 lines would occur around $J = 26-27$. So taking the intensity factor for the line R_1 (25) from the table of Laborde (1961) we find:

$$\log W_J(\max) = 1{\cdot}17 \quad \text{and} \quad 1{\cdot}26 .$$

Consequently, lines of at least 15 mA should be found in the spot observed by Branch (1969) which is contradictory to his own conclusion about the absence of C_2 Swan band lines. It appears to us that Schadee (1971) obtained much higher values for w_0/s_0 from Branch's (1969) observations than required for a complete absence of C_2 Swan band lines in the umbral spectrum.

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