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# Doppler width of CN lines in the sun

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**Abstract:** The Doppler widths of 0–1, 1–2 and 2–3 vibrational bands of the violet system of CN molecule in the solar atmosphere increase linearly with equivalent width upto ≃ 20 mÅ.

*Key words*: CN molecule—Doppler width—the sun

## 1. Introduction

The measurement and interpretation of Doppler widths of lines is a classical problem and in its various aspects has been used to determine the turbulence structure of the solar atmosphere (*cf.* Beckers & Canfield 1976; Canfield & Beckers 1976). Wehlau & Wehlau (1956), Raghavan (1968) and Porfireva (1972) have attempted to determine the turbulence velocity from the profile analysis of the lines of carbon molecules. Unno (1959) has given the depth dependence of turbulence in the solar atmosphere using Goldberg's (1958) method. Porfireva (1972) has studied the centre-to-limb variation of CN profiles and did not find any change in the Doppler widths. Tsuji (1977), while studying the first overtone lines of CO molecule, finds, that their half widths increase with equivalent widths, which may be interpreted as due to a change in turbulent velocity with depth.

In the present study, we have determined the Doppler widths of the lines of the CN violet system in the wavelength region 4139 to 4215 Å in the solar atmosphere.

## 2. Observations

Photoelectric tracings of the CN violet system were taken by a thermoelectrically cooled 1 P21 photomultiplier at the f/66, 25 cm aperture off-axis skew Cassegrain horizontal telescope system and the associated spectrograph of the Uttar Pradesh State Observatory (Pande 1975). 6, 6 and 9 lines (tables 1) of vibrational bands 0–1, 1–2 and 2–3 respectively of CN ($B^2\Sigma^+ - X^2\Sigma^+$) were traced at the centre of the solar disc in the sixth order of the spectrum at a dispersion of 0.2 Å mm$^{-1}$ with a resolution of 0.006 Å. The CN lines traced in this region are weak and blended and only lines in which the blends could be eliminated using the Utrecht atlas method (Moore *et al.* 1966) were selected. A sample of four traces is given in figure 1.

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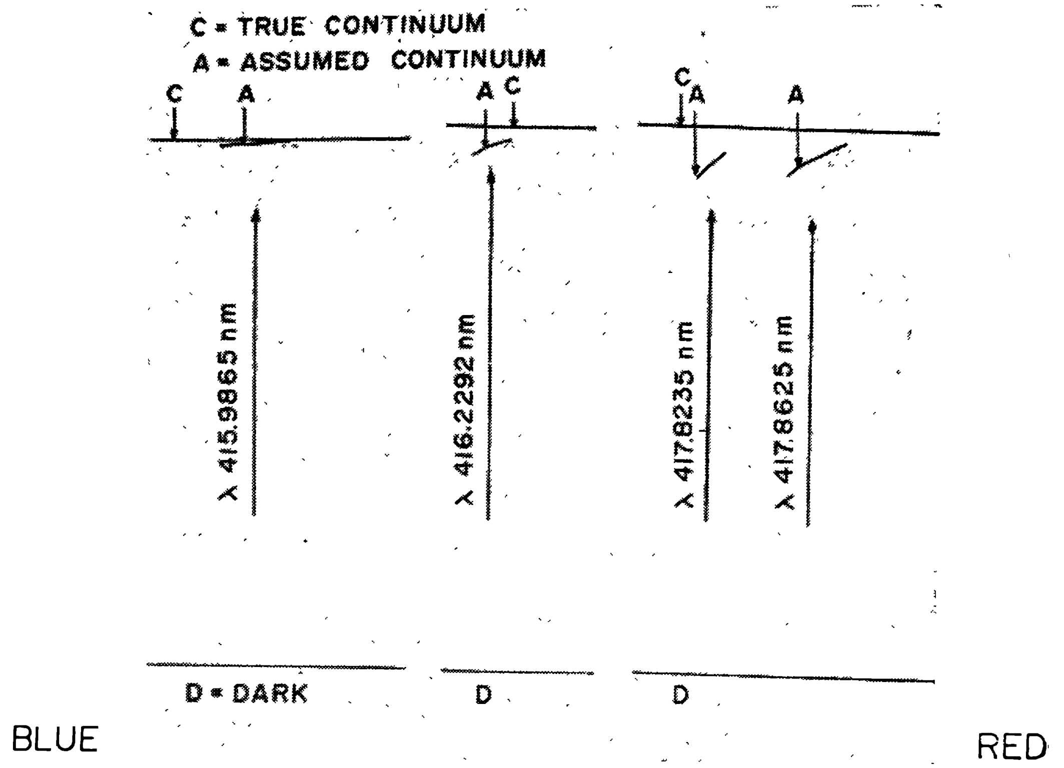

Figure 1. Sample tracings of four profils (scale tracings = 0.01 nm/mm).

## 3. Profile fitting

A Gaussian curve $R = R_0 \exp\{-(\Delta\lambda/\Delta\lambda_D)^2\}$ was fitted to the profiles after blends were eliminated. Here $R$ is the depth of the line at a distance $\Delta\lambda$ from the line centre, $R_0$ is the central depth and $\Delta\lambda_D$ is the Doppler parameter. The shape of the assumed continuum is subjective, but the probable error as taken from different trials for the same line thus introduced in both the measured parameters (*i.e.* the equivalent width and the Doppler width) lies between 2 to 7% of the tabulated values. The profiles fit the Gaussian curve with a correlation better than 0.90 (table 1). The spin doubling has been neglected for lines having low values of rotational quantum number. Following Porfireva (1972) in treating these lines as singlets, one finds that the Doppler width does not change, but their equivalent widths are additive. For wider separation in components, the profiles show 2–3% error in Doppler widths.

The Doppler width ($\Delta\lambda_D$) is found to increase linearly (table 1) with the equivalent width as

$$\Delta\lambda_D = 2.6\ W\ (\text{mÅ}) + 13.1\ (\text{mÅ}).$$

The correlation coefficient is 0.86, which is well foundedagainst the null hypothesis value of 0.413 that the correlation is accidental. Instrumental profile in our case is closely Gaussian.

## 4. Saturation effects and depth of formation

Unno (1959) has shown how scattering affects the Doppler profile if scattering is the line formation mechanism. DeJager & Neven (1959) have shown that even the

**Table 1.** Equivalent width and Doppler width measurements of photospheric CN ($B^2\Sigma^+ - X^2\Sigma^+$) molecule

| (1) Band | (2) Wavelength (Å) | (3) Line identification | (4) Equivalent width (mÅ) | (5) Doppler width (mÅ) | (6) Percentage probable error of columns (4) and (5) | (7) Correlation coefficient ($r$) | (8) Depth of formation ($\tau_{0.5\mu m}$) |
|---|---|---|---|---|---|---|---|
| 0–1 | 4214.915 | P (14) | 4.1 | 17.9 | 6 | 0.95 | 0.0017 |
| | 4214.835 | P (31) | 16.6 | 48.6 | 4 | 0.98 | 0.0015 |
| | 4214.363 | P (12) | 5.9 | 24.2 | 7 | 0.94 | 0.0018 |
| | 4212.398 | P (7) | 3.1 | 24.8 | 6 | 0.97 | 0.0023 |
| | 4205.963 | P (48) | 2 9 | 24.8 | 7 | 0.97 | 0.0023 |
| | 4205.886 | P (48) | 5.1 | 31.9 | 6 | 0.98 | 0.0023 |
| 1–2 | 4193.447 | P (39) | 11.8 | 60.0 | 3 | 0.92 | 0.0018 |
| | 4181.353 | R(9) | 10.3 | 40.1 | 2 | 0.98 | 0.0024 |
| | 4170.485 | R(19) | 5.3 | 30.2 | 6 | 0.93 | 0.0020 |
| | 4159.865 | R(27) | 16.0 | 51.0 | 2 | 0.98 | 0.0020 |
| | 4140.755 | R(39) | 15.2 | 53.1 | 2 | 0.98 | 0.0023 |
| | 4139.089 | R(40) | 9.9 | 25.0 | 3 | 0.91 | 0.0024 |
| 2–3 | 4178.625 | P (11) | 11.3 | 40.4 | 2 | 0.95 | 0.0030 |
| | 4178.235 | P (10) | 9.9 | 32.1 | 4 | 0.89 | 0.0030 |
| | 4176.990 | P (7) | 5.4 | 21.9 | 6 | 0.90 | 0.0032 |
| | 4166.100 | R(8) | 5.5 | 28.0 | 5 | 0.90 | 0.0031 |
| | 4162.292 | R(12) | 4.5 | 24.1 | 7 | 0.95 | 0.0030 |
| | 4148.395 | R(24) | 15.7 | 67.1 | 3 | 0.84 | 0.0028 |
| | 4147.213 | R(25) | 7.6 | 35 5 | 4 | 0.94 | 0.0028 |
| | 4144 768 | R(27) | 14.9 | 54.3 | 3 | 0.92 | 0.0028 |
| | 4141.652 | R(29) | 9.8 | 31.0 | 5 | 0.94 | 0.0029 |

weak lines are affected by veiling effect of the overlying continuum. In our case, the lines are formed near the temperature minimum and the veiling effect may not be very prominent. Yet to assess the role of saturation and the depth of formation, we have calculated the unsaturated and saturated line profiles for all lines of table 1. We used the photospheric model of Vernazza *et al.* (1976). Different constants were taken as follows :

Electronic oscillator strength (Arnold & Nichols 1972); Franck-Condon factors (Suchard 1975); molecular constants (Huber & Herzberg 1979); partition functions, dissociation and ionization constants (Glushko *et al.* 1962); elemental abundances (Lambert 1978); Honl-London factors (Schadee 1964); and absorption cross-sections due to $H^-$ and H, Rayleigh scattering due to H and $H_2$ and Thomson scattering (Tsuji 1966).

Following Waddell (1958) the line profiles were calculated according to the equation

$$W = \int_{-\infty}^{\infty} \int_{0}^{\infty} \Psi \cdot G \cdot (K\lambda / K\lambda_0)\, d\tau d(\Delta\lambda). \qquad \ldots(1)$$

Here $W$ is the equivalent width; $\Psi$ the saturation factor; $G$ weighting factor; $K\lambda$, the line opacity at wavelength $\lambda_0 \pm \Delta\lambda$ of the line profile; $K\lambda_0$ the continuum opacity at the line centre; and $\tau$ the continuum optical depth.

The calculated equivalent widths and Doppler widths have been found to be affected by saturation effect as :

$$W = 1.68\, W^* - 7.18 \quad (\text{correlation } r = 0.99) \qquad \ldots(2)$$

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and $\Delta\lambda_D = 0.17\ W^* - 0.64$ (correlation $r = 0.99$) ...(3)

respectively. Here $W$ is the equivalent width when $\Psi = 1$ and $W^*$ is the equivalent width when the line saturation is taken into account.

The optical depth ($\tau_{0\cdot5\mu m}$), corresponding to the half area of the contribution function ($\int_0^\infty \Psi \cdot G \cdot (K_\lambda/K_{\lambda_0}) d\tau$) for the line centre at the centre of the disc, was taken as the mean depth of formation of the lines (table 1). Since all the lines are blended and it is tedious to consider blending effect due to other species in the mean depth of formation, this $\tau_{0\cdot5\mu m}$ should be used as an indicator of the population ratio of the two levels under consideration and the oscillator strength only.

## 5. Inferences

As is clear from table 1 the lines of the 0–1 band form higher and of 2–3 band lower down in the solar atmosphere. The temperatures within this range do not change very much in the Vernazza *et al.* (1976) model. The total Doppler width $\Delta\lambda_D$ if quadratically partitioned in the temperature and turbulence part as

$$\Delta\lambda_D = \lambda/c \sqrt{2kT/m + \xi_t^2},$$

where $\xi_t$ is the turbulent velocity, gives $\xi_t$ in the range 0.6 to 3.4 km $s^{-1}$.

This method of analysis does not distinguish between micro- and macro-turbulence. Porfireva (1972) did not find any change in the Doppler width $\Delta\lambda_D$ of CN lines in going from the centre to the limb. We have obtained the Fourier transform of CH lines obtained at centre ($\mu = 1.0$) and limb ($\mu = 0.2$) and find that $\Delta\lambda_D$ increases by a factor of 1.03 in going from the centre to the limb. Similar relationship has been observed by Tsuji (1977, *cf.* figure 4) between the half widths and equivalent widths of the first overtone lines of CO molecule. He had to envisage temperature inhomogeneities of 300 K in order to reconcile his observations with the excitation temperatures and carbon abundances in different solar models. However, this does not seem to be valid since the temperature inhomogeneities of small order would get averaged out over the slit and further the temperature affects the line profile as $\sqrt{T}$, whereas the turbulence affects the Doppler width directly.

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