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Physical conditions in neutral gas atmosphere of P/Halley (1986 III) on the basis of spectral observations

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Abstract. On the basis of over 40 spectra of comet P/Halley (1986 III) obtained with the 1 m Zeiss reflector and the image-converter tube camera in Assy physical parameters of cometary gas (Q is the gas production, τ is the lifetime and v is the velocity of molecules C_2, C_3 and CN in the neutral coma) were obtained. The low velocities of the CN molecules compared to the velocities of C_2 and C_3 molecules are probably connected to the presence of the extensive source of parental molecules, from the latter as a result of photodissociation CN molecules being generated (CN-jets, CHON-particles).

Observations and reductions

The comet P/Halley was observed by Churyumov on the 1 m Zeiss reflector with the UAGS spectrograph and image-converter tube camera in Assy (near Alma-Ata). During three nights of observations (8–10 May 1986) 40 spectra of the comet and star standards in the spectral range λ = 370–630 nm were obtained. The detailed analysis of the physical conditions in the comet's head spectra with position angles 0°, 30°, 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, 300° and 330° with respect to the radius vector of the comet has been made.

The spectral negatives were photometered with a microphotometer perpendicular to dispersion in emissions CN (3883 Å), C_3 (4050 Å), C_2 (4737 Å) and C_2(5165 Å) for each position angle with a 1.98 mm diameter slit; the microphotometer magnification was 22×. As a photometric standard, the stars HD 102870 and HD 120086 were observed. The characteristic curve was constructed on the basis of processing images of the test object imprinted on the same type of emission, which were taken on the same observation nights with the help of the image-converter tube camera. Photographic densities of processing spectra were transferred to relative intensities on the basis of the characteristic curve. After reductions for the duration of the expositions and zenith distances of the comet and the standard stars as well as the expansion of the star spectrum had been introduced, outside atmosphere distributions of the surface brightness I in absolute units were calculated. For the calculations the mean coefficients of extinction on the data (Kharitonov *et al.*, 1988) were used. By integral luminosity of each line the total number of molecules of this type in the comet's head was determined by the well-known equation

$$\log N = \log E + 27.449 + 2\cdot \log (r\Delta) - \log g, \qquad (1)$$

where N is the number of molecules, E is the radiation flux from the comet's head in CGS units, r and Δ are the helio- and geocentric distances of the comet in AU, respectively, and g is the fluorescence efficiency. The fluorescence effectiveness for C_2 and C_3 molecules was taken from A'Hearn (1982), and—for CN—from Tatum (1984). The comet nucleus gas productivity for these molecules Q was calculated by the Hazer model. The scale lengths of the parental $L_{\rm par}$ and daughter $L_{\rm dau}$ molecules were taken according to Cochran (1985). The outflow velocity for calculation of the gas productivity was estimated by Delsemme's formula (Delsemme, 1982) $v = 0.58\ r^{-0.5}$, where v is in km s^{-1}, and r is in AU. Results of the calculations of the gas productivity by the Hazer model are given in Table 1.

An attempt was made to determine the characteristic lengths for the Hazer model from the emission space profiles. In order to do this, firstly, a spatial distribution of the surface brightness averaged by all position angles was constructed. By this profile, by numerical integration, dependence of the value $E(\rho)/\rho$ on the distance in the picture plane ρ from the nucleus was constructed. By the Hazer model this value is proportional to the function

$$F(\mu, x) = \int_x^{\mu x} K_0(y)\,dy + \frac{1}{x}\left[1 - \frac{1}{\mu}\right] + K_1(\mu x) - K_1(x), \quad (2)$$

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Table 1. Results of spectra processing according to the Hazer model

Emis.	Day	Log E ($\text{erg s}^{-1}\text{ cm}^{-2}$)	Log N	Ref. data L_{par} 10^4 km	Ref. data L_{dau} 10^5 km	Log Q (s^{-1})	Calculations L_{par} (10^4 km)	Calculations L_{dau} (10^5 km)
C_2	8	−8.58	31.76	7.5	3.6	26.59	2.6 ± 0.8	$\geqslant 4.3$
5160	9	−8.70	31.68	7.7	3.7	26.50	4.5 ± 1.6	$\geqslant 1.8$
	10	−8.68	31.74	7.7	3.7	26.60	5.4 ± 1.9	$\geqslant 2.1$
C_2	8	−8.75	32.36	7.5	3.6	26.78	1.2 ± 0.3	$\geqslant 4.6$
4737	9	−8.71	31.94	7.7	3.7	26.75	1.8 ± 0.5	$\geqslant 3.6$
	10	−8.65	32.03	7.7	3.7	26.89	2.3 ± 0.9	$\geqslant 4.4$
C_3	8	−8.79	31.20	0.93	4.3	27.38	0.3 ± 0.2	$\geqslant 1.8$
	9	−8.51	31.51	0.95	4.4	27.34	0.9 ± 0.5	$\geqslant 2.0$
CN	8	−8.32	31.98	5.1	9.0	27.33	1.4 ± 0.6	$\geqslant 5.5$
	9	−8.06	32.28	5.2	9.2	27.41	1.7 ± 0.9	$\geqslant 6.8$

where $\mu = L_{\text{dau}}/L_{\text{par}}$ and $x = \rho/L_{\text{dau}}$, and K_1 and K_0 are the modified Bessel functions. By the least squares optimization procedure and by the Nelder–Mead method, a problem for determining characteristic lengths with respect to the constructed dependence was solved. Regrettably, the obtained profiles had small space extensions ($x \leqslant 0.5$). Thus, the problem in question had a small sensitivity to change L_{dau}; only its lower value could be designated. The value L_{par}, due to the fact that it determines the Hazer profile along the initial sector, is evaluated with greater certainty. Results of the calculations are given in Table 1. Figure 1 shows the results of determining of the characteristic path lengths by the Hazer model for the studied profiles for 8 May. Figure 1 shows the graph of the change of the value $E(\rho)/\rho$ calculated according to the spatial distribution of the surface brightness and its approximate curve (2).

In order to determine the velocity of the gas component expansion and the lifetime of the molecules τ the obtained monochromatic profiles were processed by Shul'man's model. Within this model the surface brightness was determined by the following formula

$$I(\rho,\varphi) = \frac{A}{\rho}\left(1 - \frac{2\rho}{L_s}\cdot\sin\theta\cdot\cos\varphi\right)\cdot\int_{\rho/L_d}^{\infty} K_0(y)\,\mathrm{d}y - \frac{2A}{L_s}\cdot\cos\theta\cdot Ei(-\rho/L_d), \quad (3)$$

where A is the proportional coefficient, θ is the phase angle of the comet, $L_d = v\tau$ is the characteristic scale of the molecule path, τ is the lifetime of molecules, $L_s = 2v^2/\alpha$ is the characteristic scale of the region of the spherical symmetry, α is the radiation acceleration of molecules and Ei is the exponential integral function. The parameters L_s and L_d were determined on the basis of photometric profiles for all position angles φ. Shul'man's model describes the quasi-stationary flow of gas and supposes that velocities of flow and lifetimes of cometary molecules are constant in all the coma region. Shul'man's model does not apply to the nonstationary coma and so for the nonstationary case parameters of Shul'man's model must change with cometocentric distance. For consideration of all their possible variants with the distance from the comet's nucleus they were represented as cubic splines (Lawson and Hanson, 1974), whose coefficients were determined by equation (3) according to the least squares method obtained by optimization procedure. By the spline coefficients the behaviour of the values L_s and L_d was restored. The value L_s and L_d for molecules C_2 and CN according to Shul'man's model does not change with cometocentric distance. Variations of their values are nearly 10%, which is less than mistakes for calculating these

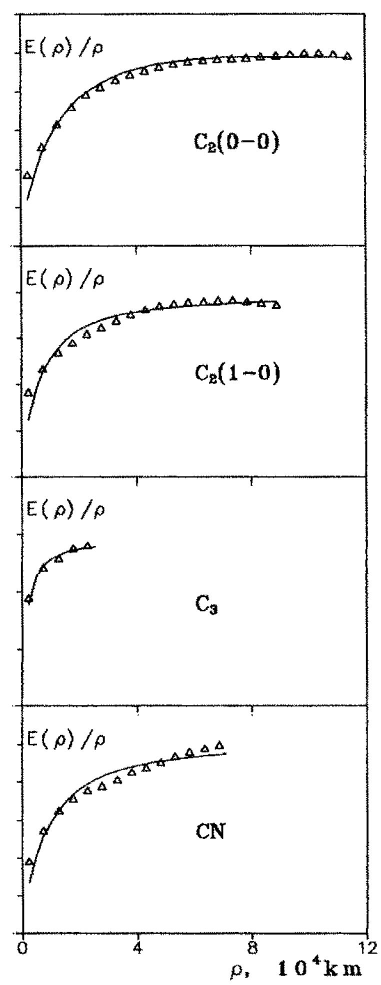

Fig. 1. The results of approximating spatial brightness profiles via the Hazer model on 8 May 1986

Table 2. Results of spectra processing according to Shul'man's model

Emis.	Day	r (AU)	$\bar{L}_s$ (10^5 km)	$\bar{L}_d$ (10^5 km)	α (10^{-3} m s^{-2})	$\bar{v}$ (m s^{-1})	$\bar{\tau}$ (10^5 s)
C_2	8	1.73	3.2 ± 0.6	11.0 ± 6.0	2.7	650 ± 70	17.0 ± 10
5160	9	1.75	3.3 ± 1.4	5.9 ± 2.3	2.6	660 ± 140	8.9 ± 5.3
	10	1.76	3.9 ± 1.6	5.4 ± 2.5	2.6	710 ± 150	7.6 ± 5.1
C_2	8	1.73	3.5 ± 1.7	4.8 ± 2.7	2.7	680 ± 170	7.1 ± 5.7
4737	9	1.75	1.9 ± 0.6	6.2 ± 4.1	2.6	500 ± 80	12.0 ± 10
	10	1.76	3.6 ± 2.0	5.5 ± 3.3	2.6	680 ± 190	8.0 ± 7.0
C_3	8	1.73	6.3 ± 2.9	2.6 ± 1.5	1.9	770 ± 180	3.4 ± 2.7
	9	1.75	3.1 ± 1.3	1.6 ± 0.9	1.8	520 ± 110	3.0 ± 2.4
CN	8	1.73	2.0 ± 0.7	1.7 ± 0.8	0.43	210 ± 40	9.3 ± 5.6
	9	1.75	1.6 ± 0.6	0.9 ± 0.4	0.42	180 ± 40	5.6 ± 3.5

values. For the molecules C_3 variations of the values L_s and L_d are near 70%—this shows that physical processes of generation C_3 molecules differ from C_2 and CN molecules.

For determination, by these data of the gas outflow velocity and its lifetime, it was necessary to determine the acceleration of the molecules. It is determined from the known values of the fluorescence efficiency via the equation

$$\log a = \log g + 11.303 - \log m - 2 \log r, \qquad (4)$$

where g and r are expressed in the same units as in (1), m the molecule mass in atomic mass units and a is the molecule acceleration in m s^{-2}. If a molecule has a number of emission bands in the spectrum, the acceleration is found as a sum of the components, each of which is determined by equation (4). The acceleration for molecule C_2 was determined by the sum of the four general bands 3635 Å, 4737 Å, 5165 Å and 5538 Å, and for CN by the sum of two 3883 Å and 4216 Å bands.

In Table 2 the averaged values of the gas parameters from Shul'man's model are given. Molecule velocities differ significantly with comparison to Delsemme's formula (0.44 km s^{-1}). Note the considerable difference in the velocity for CN. Similar behaviour of CN molecules is noted in the paper by Celnik and Schmidt-Kaler (1987). This may be caused by inaccurate determination of acceleration of the molecules, or, the more probable case, by a substantial contribution to the formation of CN—CHON and other large particles. This fact confirms the existence of CN-jets and other formations in the coma of the P/Halley.

Conclusion

According to Shul'man's model outflow velocities and the lifetimes of molecules C_2, C_a and CN have been calculated.

It has been discovered that the CN molecules have velocities nearly three times slower than those of the C_2 and C_3 molecules. It is supposed that this anomaly is caused by the existence of an extensive source or the parental molecules for CN.

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