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PHOTODISSOCIATION OF C_2 MOLECULES IN COMET ATMOSPHERE

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SUMMARY

The photodissocialtion of C_2 molecules in the atmosphere of comets is discussed starting from the most probable initial velocity v_0 of molecules C_2 and CN, the lifetime τ and the effective dissociation cross-section σ_d of the molecule C_2. The result obtained by the present author is considered as preliminary, but it is hoped that it can be further refined if the forthcoming comet photometry is performed at least as carefully as was done by Miller for the 1959K Bernham comet in 1966.

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Preliminary data on surface brightness distribution in the heads of 1942g, 1959k and other comets [1,2] show that the most probable initial velocity of C_2 and CN molecules is

$$v_0 \sim 3 \cdot 10^5 \text{ cm/sec}^{-1}.$$

With such a value of v_0 the isophots maintain a regular shape and are concentric when the light pressure acceleration is $g = 0.03$ cm·sec^{-2} for CN in the 1942g comet and $g = 0.36$ cm·sec^{-2} for C_2 in 1959k comet. For lower v_0 the effect of initial velocity dispersion and of luminescent molecule dissociation noticeably distorts the circular shape of the isophots at a distance of about 150,000 km from the photometric center for C_2 and of 500,000 km for CN the heliocentric distance being of 1 a.u.

The effect of these isophot-distorting factors appears most noticeably in the direction of the comet radius-vector. When taking into account only the velocity dispersion at constant isotropic emission, the visible density in this direction is calculated on the basis of formula

$$N(x, 0) = \frac{2n\sqrt{\pi}}{v_0 \cdot |x|} e^{-(v_1/v_0)^2},$$

where v_1 is the minimum velocity required for attaining the molecular point (x,0); and n is the number of molecules escaping per sec. steradian with velocities $v > v_1$.

If Δ is the observation error, the shape of the isophots will be circular at a value of x for which

$$1 - e^{-(v_1/v_0)^2} \leqslant \Delta.$$

Expansion in series of the left-hand part yields the condition $(v_1/v_0)^2 = \Delta$ at the point (x,0) in which the effect of dispersion on the shape of isophots is not yet noticeable. Since $v_1^2 = 2gx_1$, we obtain

$$v_0^2 = 2gx_1 / \Delta. \quad (1)$$

Formula (1) makes it possible to estimate v_0 if the values of Δ and x_1 are known.

Haser [3] shows how sharp the isophot distortion can be when overrated accelerations and underrated velocities are assigned. For instance, at $v_0 = 10^5$ cm·sec^{-1} and g = 3 cm·sec^{-2}, the deformation is already noticeable at a distance of 10,000 km from the emission center, while at higher distances the isophots cannot possibly be called circular.

With resonance radiation, acceleration g for C_2 and CN can be determined reliably enough since for these molecules, the value of oscillator forces f = 0.02 has not yet been refuted. Consequently, if the observation error Δ is known, it is possible to determine v_0.

1. Investigation of Δ for the 1959k Comet. At the request of the present author, Freeman D. Miller has investigated in detail the observation errors in studies of surface brightness distribution in C_2, i.e. in the head component of comet 1959k. F. Miller has kindly placed the results of his investigation at the disposal of the author.

Six photographs were obtained at the observatory of Michigan University by means of the Curtiss-Schmidt instrument on 103 a-J Eastman Kodak plates through an interference filter insulating the λ 5165 band of C_2. This filter transmits 7% of the head radiation R_2 (1,1) and of CO+ emission of the tail.

In the processing of photographs, we studied the isophotometer errors the effect of faulty pointing, the light dispersion by the emulsion and the effect of error in evaluating the sky background. Thus, for all practical purposes the results of surface brightness measurements may be considered as reliable.

TABLE I

r_2, km	r_1/r_2	mean error	number of isophots
7 400	1,38	±,09	7
18 800	1,13	,02	9
31 920	1,09	,04	6
51 360	1,14	,01	9
78 170	1,16	,02	10
131 390	1,16	,02	6

The isophots proved to be somewhat stretched in the direction from the Sun. With recession from the coma center, the shape of isophots becomes closer to circular. If one denotes by r_2 the radius in the direction of the Sun and by r_1 the radius in the opposite direction the deformation of isophots can be illustrated with Table 1.

This deformation may be explained: a) by the real properties of come C_2; b) by the effect of continuous emission of type II; c) by the effect of (1.1) CO^+ emission, of which 7% are transmitted by the filter.

O'Dell [4] speaks of the insignificance of continuous emission in the 1959k comet. Therefore, there is reason to believe that the deformation is caused by CO^+ emission whose maximum is somewhat shifted relative to the emission center in the direction opposite to the Sun. In any case, the dependence of isophot deformation on the distance from the photometric center compiled in Table 1 cannot be justified by the dissociation effect of C_2 molecules or by velocity dispersion at low values of v_0, for in this case $\overline{r_2 / r_1}$ would rapidly increase with the distance from the center. The latter is not confirmed by observations.

Combining his measurements with those of O'Dell [4] and Malaise [5], F. Miller determines the dependence of surface brightness S on distance d/2 (d is the maximum isophot diameter) (see Table 2).

TABLE 2

log $d/2$	3,2	3,3	3,4	3,5	3,6	3,7	3,8	3,9	4,0	4,1	
log S	3,69	3,65	3,60	3,55	3,49	3,42	3,35	3,27	3,18	3,09	
log $d/2$	4,2	4,3	4,4	4,5	4,6	4,7	4,8	4,9	5,0	5,1	5,2
log S	3,00	2,90	2,79	2,66	2,52	2,36	2,17	1,96	1,72	1,47	1,21

A preliminary study of F. Miller's materials, gives us reason to believe that at log d/2 = 5.2, the error is $\Delta \sim 0.1$ The mean deviation of the points from the smoothed curve which passes through them is ± 0.31 in log S.

Comparison of data in Table 2 with the calculations of the author [1,2] shows that with a model with an emission center

$v_0 = 3 \cdot 10^5$ cm/sec, $g = 0.36$ cm/sec^2 and $\tau = 3 \cdot 10^4$ sec. we obtain a complete coincidence between the observations and the calculations for $\log d/2 \geqslant 4{,}1$, i.e. for $d/2 > 12{,}000$ km. At lower d/2 values the calculated value of S exceeds the measured one (Table 3).

TABLE 3

$\log d/2$	3,47	3,78	4,08	4,25	4,38	4,57	4,78	4,95	5,03	5,18
$\log S$	3,91	3,47	3,19	2,98	2,81	2,67	2,16	1,79	1,48	1,21

The fact that at d/2 10,000 km $S_{cal} > S_{obs}$ is easily explained by the peculiarity of our model. At low d/2 we approach the region filled with parent molecules. To simplify the model we assumed this region to be a point. Therefore, as $d/2 \to 0$ $S \to \infty$ In reality this region may have a radius of several hundred km. Therefore, at low d/2 values the calculated surface brightness must be higher than those observed. However, it should be remembered that a decrease in S_{obs} may also be the result of photographic overexposure. Therefore, it should be concluded that both observers and theorists must concentrate their attention on the internal regions of comet's head which are close to the photometric center.

2. On the Possibility of C_2 Photodissociation by the Far Ultraviolet Solar Radiation. The explanation of surface brightness distribution by the dispersion of initial velocities, contained in Table 2, looses its validity following a study of F. Miller's measurements in the direction of the Sun. At $v_0 = 5 \cdot 10^4$ cm/sec, the dispersion of initial velocities yields a value of log S near that of Table 2. However, it generates a sharp asymmetry in the distribution along the radius-vector, and this is in contradiction with the observations.

In studying the possibility of C_2 photodissociation it should be noted that the surface brightness distribution obtained by Miller necessitates in our model the satisfaction of the condition

$$v_0 \tau \sim 9.10^9 \text{ cm},$$

which virtually coincides with the condition derived by Yu.N. Gnedin and A.Z. Dolginov [6]:

$$v_0 \tau \sim 10^{10} \text{ cm},$$

where τ is C_2 molecule lifetime prior to dissociation and v_0 is the most probable velocity.

S.M. Poloskov [7] obtained for C_2 in 1948 $\tau = 0.5$ hr. At this value of τ the Miller distribution requires $v_0 = 5 \cdot 10^6$ cm/sec. Such a value of v_0 seems to us of little probability. To obtain similar velocities, colossal energy absorption is required during the dissociation of parent molecules. Indeed, only $^1/_2\ mv_0{}^2 = 312$ ev.

The photodissociation of C_2 with subsequent excitation of atom C seems more probable. Astronomer V.A. Ambartsumyan [9] obtains in this case $\tau \sim 3 \cdot 10^7$ sec whence C_2 is not subject to dissociation during the whole time of its stay in the head and tail of the comet. The reason for this conclusion is due to the fact that in 1939 there was no information on the true solar radiation in the far ultraviolet, on surface brightness distribution in the coma, and on energies of C_2 dissociation and C excitation.

According to contemporary data, the energy of C_2 dissociation is 3.6 ev [10], while the energy of C excitation is 7.48 ev [11]. Therefore, photodissociation of C_2 requires the absorption of quanta with energy $E \geqslant 11.1$ ev, i.e. $\lambda \leqslant 1120$ Å.

According to Hinteregger [7] for $\lambda \leqslant 1120$ Å

$$\Phi = 2.7 \cdot 10^{11} \text{quanta/cm}^2\text{sec},$$

while in order to obtain $\tau = 3 \cdot 10^4$ sec it is necessary that the effective cross-section of the photodissociation be

$$\sigma_d = 1/\Phi\tau = 1.2 \cdot 10^{-16}\ \text{cm}^2.$$

If we compute the absorption coefficient according to formula [8]

$$\int\limits_{\nu_0}^{\infty} \varkappa_\nu d_\nu = \frac{\pi e^2}{mc} f,$$

by postulating $\kappa = \alpha/\nu^3$ we have

$$\sigma = \frac{2\pi e^2 \lambda_0}{mc^2} f = 2{,}1 \cdot 10^{-17} f.$$

Postulating $f = 1$, we see that the calculated value of the effective cross-section is six times lower than the one we require.

It is essential to bear in mind that the calculated value $\sigma = 2.1 \cdot 10^{-17}$ cannot be considered as reliable. As is shown in the investigations of numerous authors, the ν^{-3} law, is not accurate nor is the accepted value f = 1.

O.V. Dobrovol'skiy has compiled ([7] p. 76) a Table of ionization and dissociation probabilities for O_2, CH_4, H_2, H_2O molecules. He points out that for these molecules the probability of dissociation is higher by approximately one order than the probability of ionization. Therefore, the $\sigma_d = 1.2 \cdot 10^{-16}$ cm^2 obtained by us for C_2 should be viewed as a preliminary result of experimental determination of the effective dissociation cross-section. If the forthcoming comet photometry is conducted no less carefully than the way it was done by Freeman D. Miller in 1966 for the 1959k Bernham comet, corroboration and more refined values of v_0, τ and σ_d can be anticipated in the future.

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