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Abstract

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ON THE PHOTODISSOCIATION OF C_2 MOLECULES IN THE ATMOSPHERE OF COMETS

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Preliminary data on the distribution of surface brightness in the heads of comets 1942g, 1959k, and others (^{1,2}) show that the most probable initial velocity of the molecules C_2 and CN is

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

At this value of v_0 and at a light-pressure acceleration $g = 0.03$ cm $\cdot$ s^{-2} for CN in comet 1942g and $g = 0.36$ cm $\cdot$ s^{-2} for C_2 in comet 1959k, the isophotes retain a circular form and are concentric. For smaller values of v_0, the influence of the dispersion of the initial velocities and of the dissociation of the luminous molecules noticeably distorts the circular form of the isophotes at distances of about 150,000 km from the photometric center for C_2 and 500,000 km for CN at a heliocentric distance of 1 AU.

The influence of these factors, which distort the form of the isophotes, is most noticeable in the direction of the comet' s radius vector. In this direction, when only velocity dispersion is taken into account for constant isotropic emission, the apparent density is calculated by the formula

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

where v_1 is the smallest velocity necessary for a molecule to reach the point $(x, 0)$; n is the number of molecules flying out in 1 s into a steradian with velocities $v \geq v_1$.

If Δ is the observational error, then the form of the isophotes will be circular at a value of x for which

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

Expansion of the left-hand side in a series gives the condition $(v_1/v_0)^2 = \Delta$ at the point $(x, 0)$, where the influence of dispersion on the form of the isophotes is still not noticeable. Since $v_1^2 = 2gx_1$, we obtain

$$v_0^2 = 2gx_1/\Delta. \tag{1}$$

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

Haser' s work (^{3}) shows how sharp the distortion of isophotes can be when overestimated values of accelerations and underestimated velocities are specified. For example, at $v_0 = 10^5$ cm $\cdot$ s^{-1} and $g = 3$ cm $\cdot$ s^{-2}, the deformation is noticeable already at a distance of 10,000 km from the emission center, and at greater distances the isophotes can in no way be called circular.

The acceleration g under resonance radiation is determined rather confidently for C_2 and CN, since for these molecules the values of the oscillator strengths $f = 0.02$ have not yet been disproved. Consequently, v_0 can be estimated if the observational error Δ is known.

1. Study of Δ for comet 1959k. At the author's request, D. Miller of Frimen thoroughly investigated the observational errors in studying the distribution of surface brightness in the C_2 component of the head

comet 1959k. The results of this study were kindly made available to the author by F. Miller.

At the University of Michigan Observatory, 6 photographs were obtained with the Curtis–Schmidt instrument on Eastman-Kodak 103 a-J plates through an interference filter isolating the λ5165 bands of C_2. This filter transmits 7% of the radiation from the head of the $(1, 1)$ R_2 band and of the CO^+ tail radiation.

In processing the photographs, the errors of the isophotometer, the effect of poor guiding, light scattering by the emulsion, and the influence of the error in estimating the sky background were studied. Therefore the results of the surface-brightness measurements may be regarded as practically reliable.

Table 1

r_2, km	r_1/r_2	Mean error	Number of isophotes
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 isophotes proved to be somewhat elongated in the direction away from the Sun. The shape of the isophotes approaches a circle with increasing distance from the center of the coma. If by r_2 we denote the radius in the direction toward the Sun, and by r_1 that in the opposite direction, then the deformation of the isophotes can be illustrated by Table 1.

Such a deformation can be explained by: a) the true properties of the C_2 coma; b) the influence of continuous radiation of a type-II tail; c) the influence of $(1, 1)$ CO^+ radiation, 7% of which is transmitted by the filter.

But O’ Dell’ s paper (4) speaks of the insignificance of continuous radiation in comet 1959k; therefore one should think that the deformation is caused by CO^+ radiation, whose maximum is displaced somewhat relative to the center of emission in the direction opposite the Sun. In any case, the dependence of the deformation of the isophotes on the distance from the photometric center given in Table 1 cannot be explained by the effect of dissociation of C_2 molecules or by velocity dispersion at small values of v_0, because in this case r_2/r_1 would increase rapidly with distance from the center. The latter is not confirmed by the observations.

Combining his measurements with those of O’ Dell (4) and Males (5), F. Miller gives the dependence of the surface brightness S on the distance $d/2$ (d is the greatest diameter of an isophote) (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
$\log S$	3.00	2.90	2.79	2.66	2.52	2.36	2.17	1.96	1.72	1.47

A preliminary study of F. Miller’ s material suggests that the error is $\Delta \sim 0.1$ at $\log d/2 = 5.2$. The mean deviation of the points from the smoothed curve passing through them is ± 0.31 in $\log S$.

Comparison of the data in Table 2 with the author’ s calculations (1,2) shows that, for a model with 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 complete agreement of the observations with the calculations for $\log d/2 \geq 4.1$, i.e., for $d/2 > 12\,000$ km. At smaller values of $d/2$, 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	4.47	4.78	4.95	5.08	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 for $d/2 < 10\,000$ km $S_{\text{calc}} > S_{\text{obs}}$ is easily explained by a peculiarity of our model. At small $d/2$ we approach the region filled by parent molecules. To simplify the model we assumed this

region into a point; therefore $S \to \infty$ as $d/2 \to 0$. In reality this region may have a radius of several hundred kilometers. Therefore, for small values of $d/2$, the calculated surface brightnesses should be greater than the observed ones. But it must be remembered that a decrease in S_{obs} may also result from overexposure during photography. Hence one should conclude that both observers and theorists must concentrate their attention on the inner regions of the comet' s head, close to the photometric center.

2. On the possibility of photodissociation of C_2 by the extreme ultraviolet radiation of the Sun. The explanation of the surface-brightness distribution presented in Table 2 by a dispersion of the initial velocities is automatically ruled out after studying the measurements of F. Miller in the direction toward the Sun. A dispersion of the initial velocities at $v_0 = 5 \cdot 10^4$ cm/sec gives $\log S$ close to that given in Table 2, but produces a sharp asymmetry in the distribution along the radius vector, which contradicts the observations.

In studying the possibility of photodissociation of C_2, it is necessary to note that the surface-brightness distribution obtained by Miller, in our model, requires fulfillment of the condition

$$v_0 \tau \sim 9 \cdot 10^9 \text{ cm},$$

which practically 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 the lifetime of the C_2 molecule before dissociation; v_0 is the most probable velocity.

For C_2, C. M. Poloskov (^{7}) obtained in 1948 $\tau = 0.5$ hour. At this value of τ, Miller' s distribution requires $v_0 = 5 \cdot 10^6$ cm/sec. Such a value of v_0 seems to us improbable. To obtain such velocities, absorption of a colossal energy during dissociation of the parent molecules is necessary. Indeed, $\frac{1}{2} m v_0^2 = 312$ eV.

Photodissociation of C_2 with subsequent excitation of the C atom appears more probable. In this case V. A. Ambartsumian (^{9}) obtains $\tau \sim 3 \cdot 10^7$ sec, whence it is necessary to conclude that C_2 does not undergo dissociation during the entire time it remains in the head and tail of the comet. The reason for this conclusion is that in 1939 there was no information about the actual radiation of the Sun in the extreme ultraviolet, about the surface-brightness distribution in the coma, and about the energies of dissociation of C_2 and excitation of C.

According to modern data, the dissociation energy of C_2 is 3.6 eV (^{10}), and the excitation energy of C is 7.48 eV (^{11}); therefore, for photodissociation of C_2, absorption of quanta with energy $E \geq 11.1$ eV is necessary, i.e. $\lambda \leq 1120$ Å. According to Hinteregger (^{7}), for $\lambda \leq 1120$ Å

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

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

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

If the absorption coefficient is calculated by formula (8)

$$\int_{\nu_0}^{\infty} \chi_\nu d\nu = \frac{\pi e^2}{mc} f,$$

assuming $\chi = a/\nu^3$, then we obtain

$$\sigma = \frac{2\pi e^2 \lambda_0}{mc^2} f = 2.1 \cdot 10^{-17} f.$$

Assuming $f = 1$, we see that the computed value of the effective cross section is 6 times smaller than the value we require.

It must be noted that the computed value $\sigma = 2.1 \cdot 10^{-17}$ cannot be regarded as certain. The law ν^{-3}, as studies by many authors show, is not exact, nor is the adopted value $f = 1$.

O. V. Dobrovolsky gives ([(7), p. 76]) a table of ionization and dissociation probabilities for the molecules O_2, CH_4, H_3, H_2O, and draws attention to the fact that the probability of dissociation for these molecules is approximately an order of magnitude greater than the probability of ionization. Therefore $\sigma_d = 1.2 \cdot 10^{-16}$ cm^2, obtained by us for C_2, should be regarded as a preliminary result of an experimental determination of the effective dissociation cross section. In the future one may expect confirmation and refinement of the quantities ν_0, τ, and σ_d, if photometry of comets is carried out no less carefully than was done by D. Miller in 1966 for Comet Burnham 1959k.

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Note: Figure translations are in progress. See original paper for figures.