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PHOTOMETRY OF THE COMETARY ATMOSPHERE: A Review

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1. INTRODUCTION

Photometry and polarimetry of the cometary heads still constitute one of the most important sources of information about the physical processes in comets. For instance, most of the present estimates of molecular lifetimes are based on the observed distribution of molecules in the cometary head and the assumption of a particular kinematical behaviour of the matter in the cometary atmospheres.

The study of kinematics and dynamics of cometary heads and tails has been based upon the analysis of the forms and apparent motions of well-defined envelopes, halos, knots in tails and streams. Direct inspection of a large number of photographs (or drawings from the last century) of several bright comets demonstrates that the cometary head is generally a complicated object. The heads consist of nearly circular diffuse patterns with superposition of different features, particularly of curved streams. This is illustrated by the Atlas of the Cometary Forms compiled by Rahe, Donn and Wurm (1970).

Comets of small apparent dimensions exhibit few features which could be observed directly and could be used for the interpretation of physical processes. Therefore, for many comets the information available for comparison with theories of the mechanism and tail or head formation was obtained mostly only from the study of distribution of the surface intensity.

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It is, however, essential that the observations should refer, as far as possible, to the radiation emitted or reflected by different kinds of particles (dust, C_2, C_3, CN, CO^+, etc.). It is, therefore, evident that the interpretation of the structure of comets requires monochromatic observations.

Direct unfiltered photography is still valuable for the continuous monitoring of the rapidly changing cometary phenomena—as, for instance, of some features in the tail. It is almost useless for other information about the processes in cometary bodies. The amount of useful monochromatic observations of comets has been still lamentably poor in the past decades—in contrast to the photometry of stars and nebulae, where rapid progress has been achieved. The number of comets observed with adequate modern techniques is small and limited mostly to bright objects observed since 1956. A most dissatisfying circumstance is the fact that photographic and photoelectric observations do not usually lend themselves to the transformation of the absolute photometric scale into isophotes which can be obtained with high angular resolution only from large-scale photographs.

The best discussion of this problem is in a short review by F. D. Miller in the Appendix to "Report on Planned Programme for Comet Kohoutek 1973f" by Brandt, Rahe and Vanysek (1973).

Table 1

Narrow-Band Filters for Standard Cometary Photometry and Photography (Recommended)

Cometary Emission	λ_{max}(Å)	FW(Å)
CN	3880 4738	70 to 80 50 to 60
C_2	5170	50 to 60
CO^+ (tail)	4267	<50
Na	5893	<50

λ_{max} = wavelength of the maximum transmission
FW = full width at half maximum

Table 2

Sample of the Narrow-Band Filters Used for Photometry of CN, C_2 and Continuum*

Author	CN	C_2	Continuum
Bappu et al. (1967)	3859(163)	4720(71)	4310 4860(65) 5875(97)
Vanysek (1969)	3880(240)	4740(90)	4860(180)
Miller (1969)		5136(96)	4850(64)
Konopleva et al. (1970)		4740(190) 5225(480)	4380-4470 4750-4840 5640-5700
Borra et al. (1971)	3878(95)	5117(95)	4870(95)
Kohoutek (1974)	3892(42)	4747(58) 5180(78)	5306(73)

*Four digits are peak transmission wavelength and in parentheses the width at half maximum; both in Å.

2. PRESENT STATE OF COMETARY PHOTOMETRY

Even though the narrow-band photometry is being used more extensively, the available photometric observations of comets suitable for the study of the different compounds' distribution are still lacking, and only a few homogeneous sets of observations have been obtained. The paucity of accurate photometric observations of comets in monochromatic light is due merely to the fact that it is very difficult to reconcile the needs of cometary photometry with those of stellar photometry.

The results obtained from the wide-band photometry must be regarded as tentative only, unless it is quite evident that either continuum or emission bands were absent in the spectral region studied. There is only one exception: the photometry and photography obtained with red filter (e.g., Schott RG 1) provide data for the dust part of the coma or tail. But in other visual spectral regions the situation is more complicated. One can, for instance, hardly make some reasonable conclusion about the dimension and shape of the CN or C_2 coma because of overlapping with CO^+ features.

The acceleration of CN and C_2 molecules due to the light pressure estimated from the oscillator strength for typical bands is 0.3 to 0.5 cm sec^{-2} at 1 AU and leads to some deformation of the CN and C_2 isophotes by shifting them slightly into the tail direction. However, the kinematics of CO^+ ions required obviously larger accelerations thus the typical "onion-like" form of the isophotes obtained from measurements near the CN emission pass-bands is due to the overlap of the CN and CO^+ emission and, of course, also to the scattered light on the dust particles. This effect can easily be demonstrated in many direct photographs or even on the isophotometry charts.

The colour photography is one of the very efficient methods for a direct inspection of dust and gaseous forms in comets. Photographic colour emulsions with very low reciprocity failure are available and show promise in the study of cometary structure and morphology. An example of the possibilities was shown by Dr. J. C. Brandt by a colour photograph of Comet Bennett which showed the dust tail as yellow and the ion tail as blue. A black-and-white photograph of the comet taken at approximately the same time did not permit the two tail types to be easily distinguished.

In the visual region the UBV colour system used in routine stellar photometry is inadequate for cometary photometry. The unusual intensity distribution in cometary spectra means that the colour of the comet cannot be transformed to any conventional colour system. The U-filter covers practically only CN bands (3880 Å) while the V- and B-filters include the most prominent band sequences of C_2. The C_3 emission and most of the CO^+ lines are in the range of the B filter. Only from the U-B colour, which is more sensitive to the behaviour of cometary spectra, the relative contribution of CN to C_2 may be qualitatively estimated.

Somewhat more suitable for cometary photometric studies is the uvby system combined with the H_β narrow pass-band filter. The H_β and b filters can be used for the determination of C_2 $\Delta v = +1$ emission band and continuum flux near the H_β wavelength. The region close to 4860 Å is not strongly contaminated by molecular emission and, therefore, the H_β photometry combined with a wide-band filter seems to be the best "two-colour system" for routine photometry of faint comets. Also measurements in the near infrared—i.e., R and I—may sometimes be contaminated by molecular emission, particularly by the CN red system.

For practical purposes the colour difference D may be introduced, defined by

$$D = (U-B)_{comet} - (U-B)_s$$

where $(U-B)_{comet}$ is the colour corresponding to the comet, and $(U-B)_s$ are the colours for the Sun or stars with the continuum distribution similar to the distribution in the cometary continuum. When D = 0 no emission of CN is present. The value of D increases with molecular emission up to the maximum value which depends on the filters' transmission at 3880 Å.

A very serious problem is the fact that most parts of the available photometric data of comets have been usually obtained from observations which were made at large zenith distances. Therefore, their accuracy cannot be compared with those achieved by routine photoelectric methods, and absolute flux values are about 10% or more uncertain in contrast to the relative intensities of nearby passbands which may be precise enough when, for instance, a tilting filter technique is applied.

This method was used recently by Barbieri et al. (1974) for the determination of the continuum flux at 8560 Å and 8748 Å of Comet Kohoutek 1973f, by means of a narrow Fabry-Perot filter. The advantage of solid etalons in wavelength scanning by tilting is an extensive exploit in atmospheric studies and even weak emission can be identified. By a tilting method it can be easily demonstrated that the continuum of Comet Kohoutek was free of any molecular emission around 8750 Å. However, such observations are unique and limited to bright comets.

Valuable observations were obtained by a photoelectric spectrum scanner by O'Dell and Mayer (1968) for Comet Rudnicki (1966e), and by Gebel (1970) for Comets Ikeya-Seki (1967a), Honda (1968c) and Thomas (1968b). A similar observational method was applied by Babu and Saxena (1972) to Comet Bennett (1969i) and by Babu (1974) to Comet Kohoutek (1973f). Unfortunately, these observations had relatively low angular (and space) resolution.

From poor space resolution suffer, to some extent, also the photographic measurements which were used for studying the molecular density distribution in the cometary heads. (See Vorontsov-Velyaminov (1960), Vanýsek and Žáček (1967), Dewey and Miller (1966), Borra and Wehlau (1971, 1973).) The best material of this kind with high angular resolution (about 14''/mm) in monochromatic light has been obtained by Rahe et al. (1974).

Perhaps the most important photometric data (with regard to the photometric profiles of cometary neutral atmospheres) have been obtained by Malaise with the aid of his six-channel photometer with adjustable wavelength and passbands (Malaise, 1970); but a considerable amount of his observations were still recently being reduced. The instrument itself was recently attached to the 2-meter Ondrejov telescope, but very bad weather conditions in January 1974 permitted only one incomplete observation of Comet Kohoutek made by Malaise and the author of this report.

3. RECENT RESULTS

From preliminary reports obtained by many observers an unusually great number of photoelectric observations of comets has been obtained very recently. Both bright Comets Kohoutek 1973f and Bradfield 1974b were observed so extensively that the observations are only partly reduced and the following summary represents only a small sample of the results.

A very large and homogeneous set of photoelectric and infrared measurements before the perihelion passage of Comet Kohoutek was published by Rieke and Lee (1974). Their results are important for the interpretation of infrared radiation (particularly the 10μ "bump") of the dust in the cometary atmosphere. The data for UBVRI colours may, however, provide only rough information about the behaviour of the continuum radiation of the comet in the first half of October 1973, when the contribution of the emission bands was negligible. After October

16, the emissions of CN and C_2 bands in the spectrum of the comet were apparent and only observations in narrow pass-bands might provide exact data for the determination of albedo of the dust particles, by a comparison of the integrated surface brightness in the infrared and surface brightness of the scattered light in the visual spectral region. Therefore, the numerical expression involving albedo derived by Rieke and Lee should be considered to be only very preliminary. Their data in the UBVRI system for different diaphragms indicate that the colour index B-V of the inner part of the coma was almost the same as that of the Sun while the outer region shows a decrease of the index U-B which was probably due mainly to the CN band.

One of the sets of pre-perihelion observations in the narrow pass-bands was obtained by Babu (1974), with the spectrum scanner (Babu, 1971) measuring the intensities in the pass band about 35 Å in the range 3700 to 6400 Å. His results indicate that absolute fluxes of CN emission at 3880 Å varied approximately with r^{-2} while C_2 and C_3 bands increased with r^{-4} in the interval of heliocentric distances $r = 0.73$ to 0.52. But because the change of geocentric distance was very small and the radius of the coma measured with a fixed diaphragm was almost constant (about 4×10^4 km), a fast increase of the C_2 and C_3 intensities with decreasing r was due, partly at least, to a decrease of the length scale of the parent particles rather than to an increase in the abundances of these molecules. This effect was caused by a shrinking of the gaseous coma which, for small diaphragms, is more pronounced for C_2 emission than for CN.

This fact was confirmed by the photometric data submitted by Cowan and A'Hearn (1974) which provided the total flux in the C_2-band sequence at 4700 Å measured in a very large diaphragm 116 and 193 arcsecs corresponding to the coma diameter about 10^5 and 1.8×10^5 km in the interval from December 1 to December 7. The luminosity of the C_2 (0, 1) band remains essentially the same—about 2×10^{19} erg sec^{-1}—in the time interval between December 2 and December 7 and was slightly lower than on December 1.

The results obtained by Babu for the continuum energy distribution in the head of Comet 1973f indicate some reddening of the scattered light with respect to the Sun, decreasing with phase angle ϕ (in the interval $\phi = 51°$ to $57°$) and with heliocentric distance so that the reddening disappeared on December 17.

The positive colour excess has been confirmed in several comets (Walker, 1958; Bappu and Sinvhal, 1960; Liller, 1960; Vanysek, 1960; Kharitonov and Rebristyi, 1974). Some spectrophotometric results lead to the conclusion that the colour of comets resembles the spectral distribution of G8 V stars and this reddening may be attributed to selective light scattering on small dust particles. However, the results obtained by Gebel (1970) for Comets 1968 I, 1968 V and 1968 VI show that the spectral distribution of continuum was "grey"—i.e., it coincided with the colour of the Sun.

In the case of Comet Kohoutek, measurements of the continuum spectral distribution were made at very large zenith distances where some uncontrollable influence of anomalous extinction must be expected. Therefore, it is not quite certain that the differences with respect to the solar continuum are real.

Post-perihelion photoelectric observations have been made by Kohoutek of his bright comet in the UBV system as well as in the pass bands near λ(Å) = 3880 (CN); 4267 (CO^+); 4738, 5172 (C_2); 5300 (continuum) and one centered on the sodium doublet.

This set of observations covers the range of heliocentric distances r from 0.65 to 1.0 AU. Kohoutek reported that measurements in the 4267 Å pass-band indicated a negligible intensity of CO^+ bands in diaphragms 40 and 80 arcsecs and the measured intensity virtually refers only to the continuum radiation. Emission of the sodium doublet was detected only on January 15 and 16, but at the heliocentric distances 0.7 to 1.0 AU the sodium lines (if any) were very weak. It must be noted that the intensity of NaI emission before perihelion passage was obviously also low, as follows from the above-quoted measurements made by Babu. If the results obtained by Kohoutek for 4267 Å, 5300 Å and 5890 Å are interpreted as intensities for the continuum, then solar radiation scattered on the dust particles exhibited some red excess, which is in agreement with the selective "reddening" of the cometary continuum observed in several previous comets studied photometrically and spectrophotometrically. The estimated contribution of the C_2 $\Delta v = 0$ band to the continuum in the V-colour was about 1:0.7, and about 1:1 in the B-colour where, of course, $\Delta v = +1$. The C_2 band as well as the CN band dominates in the U-colour where the band/continuum ratio was about 1.66 (for a heliocentric distance $r = 1$ AU).

The dust coma, according to these measurements, was more concentrated toward the nucleus than the CN and C_2 atmospheres. The "colour effect" described by Vanysek (1960, 1966)—i.e., an increase of the colour index with diameter of the diaphragm, is quite evident in B-V from Kohoutek's measurements. The absolute colour indices in the 40 and 80 arcsec diaphragms increase slightly in BV from 0.85 to 0.94. The magnitude difference Δm of the measurements in two diaphragms with the radii $\rho = 40$ and 80 arcsec indicates a deviation from the surface intensity law ρ^{-1} for a spherically symmetric coma. The deviation can be expressed by ρ^{-n} where $n < 1$, and is due to the "flatness" of the photometric profile of the inner part of the coma where visible radicals are produced from parent particles. This means, of course, that the "zone of production" for C_2 and CN was traced at least up to 4×10^4 km from the nucleus.

Kohoutek found that the comet's brightness decreased after the perihelion passage more rapidly in the inner part of the coma (with $r^{-4.6}$ to r^{-5}) than in the outer one ($r^{-3.6}$ to $r^{-4.2}$). A very rapid change in surface intensity was observed photoelectrically by Mrkos and Vanysek in Comet Bradfield 1974b. This is merely a well-known effect due to the coma expansion with increasing heliocentric distance r—i.e., a reversal of the pre-perihelion shrinking of the cometary head.

Although the results discussed here and obtained by Babu, Kohoutek and Cowan and A'Hearn represent not quite homogeneous sets of observations, the pre-perihelion and post-perihelion total luminosity of the C_2 (4734 Å) Swan-band can be compared. If the available data are reduced to the heliocentric distance r = 1 AU and to the diameter 5.5×10^4 km then the post-perihelion luminosity decreases by a factor of about 10:

pre-perihelion $F_0 = 2 \times 10^{18}$ erg sec^{-1} (from Cowan and A'Hearn's observations);

post-perihelion $F_0 = 1.5 \times 10^{17}$ erg sec^{-1} (Kohoutek).

The post-perihelion decrease of the luminosity of CN seems to be not so sharp. The relative intensities of the CN band in December 1973 obtained by Babu are considerably lower than those of the C_2 $\Delta v = 0$ band but the post-perihelion results reported by Kohoutek indicate that the CN emission was slightly more luminous than that of the C_2 main band. Therefore, the luminosity of CN (reduced again to r = 1 AU and the same area) was lower after the perihelion passage only by a factor of about 2.5 to 3. A considerable diminution in luminosity occurred in the continuum, as follows from almost all available observations.

One can believe that Kohoutek 1973f was a "normal" comet and the relatively high brightness at large heliocentric distances shortly after discovery till the beginning of October 1973 may be attributed to dust clouds surrounding the central condensation (or nucleus), which diminished slowly when the comet was approaching the Sun. This means that at least this particular comet may be described as a nucleus surrounded by a swarm of dust particles from which the very small (and volatile) ones were expelled and evaporated beyond $r \geqslant 0.8$ AU. Barbieri et al. (1974) concluded from the near-infrared observations at 8560 and 8748 Å that the dust production rate decreased by a factor of 10 relatively to the gas production in the post-perihelion period.

Although the above discussed results are somewhat incomplete, it is evident that C_2 emissions are more sensitive to a change of dust content than the CN band. Unfortunately, the luminosities of bands of molecular origin are not sufficient for the determination of the production rate without knowledge about kinematics and lifetime scale of the respective compounds. However, there is strong indication that the C_2 production rate depends on the dust contents in the cometary atmosphere (and, consequently, on dust production) more than CN and perhaps other molecules.

4. POLARIMETRIC MEASUREMENTS

The available polarimetric data of Comet Kohoutek are only few and must be considered only as preliminary. Michalsky (1974) reported polarization measurements made by Avery, Stokes, Zellner, Wolstencroft and himself at three observatories in Hawaii, Arizona and Washington State. Pre- and post-perihelion observations were made with broad and narrow filters, which included or excluded emission lines and/or bands. All measurements were centered on the coma condensation with apertures ranging from 15-40 arcsecs in diameter. As for Comet Bennett 1969i, higher linear polarization was observed in the red than in the blue. Rayleigh scattering is excluded because of the colour of the comet.

The maximum of linear polarization was found by Avery on January 9—26%—in B colour, and Zellner (also 26%) on January 16 in the close area (15 arcsecs) around the central condensation.

Measurements made in adjacent spectral regions when emission was included and excluded indicate that the magnitude of the polarization is higher in emission—this unusual effect has not been reported previously. Other measurements bear out this behaviour after perihelion passage as well as before. Because the polarization of the molecular bands should be only 8 to 10% this effect must be analyzed again very carefully. All measurements showed the direction vector to be rigidly perpendicular to the scattering plane.

Michalsky noted that the light scattered from nonspherical aligned particles should show a small circularly polarized component. A search for this component led to a value of 0.02 ± 0.06% showing that no large effect is present, but observations indicated an increase of linear polarization with decreasing aperture, which may imply alignment possibly contradictory to the previous discussion.

The most important results concerning the polarization of the cometary light are those reported by Weinberg; however, these did not concern the comet's head but the tail. A multicolour photoelectric polarimeter was used at Mt. Haleakala Observatory to observe the tail of Comet Ikeya-Seki (1965 VIII) on 4 nights following perihelion on 21 October 1965. Observations were made at six continuum wavelengths and with two different filters centered at the 5577 Å emission of OI. From preliminary results only the observations at 5400 Å on 28/29 October 1965 are available. Measurements were made by scanning at 0.5 deg/sec over a 9 x 20 deg section of the sky containing the comet: in azimuth, from 105 to 114 deg (90 = east), and in elevation, from 0 (horizon) to 20 deg in steps of 1.0 deg. This method of scanning provides considerably more information in the direction normal to the axis of the tail of the comet and the intensity can be easily derived from the total brightness (radiance) of background plus comet for different zenith angles.

Of particular interest is the change in polarization between 6 and 7 deg elevation (approximately 11 deg from the nucleus). Since the background (primarily zodiacal light) and comet radiations are independent, their Stokes parameters are additive. The polarization of zodiacal light in this area is positive—i.e., the electric vector is perpendicular to the scattering plane. Only negative polarization at distances greater than 11 degrees from the nucleus can produce the observed net decrease in total polarization in the direction of the comet tail.

The comet was ideally positioned with respect to the main cone of the zodiacal light, and the separation of the comet from the smooth fall-off in total brightness is easily accomplished. The sharp change of orientation of the polarization plane (orientation of the electric vector) with the phase angle is very typical for the polydispersed optically thin cloud containing particles with very low imaginary part of the refractive index. Therefore, the polarization data obtained by Weinberg are compatible with infrared results at $\lambda = 10\mu$ where the emission-like peak (observed in spectra of Comets Bennett and Kohoutek) may be ascribed to dielectric silicate particles (Maas et al. (1970), Ney and Ney (1974), Kleinmann et al. (1971)).

Moreover, negative polarization (with respect to the orientation of the electric vector) as in the case of zodiacal light, requires the presence of dielectric or irregularly-shaped particles. The use of additional observations at several wavelengths at different times, as Weinberg suggests, may single out a rather small family of permissible solutions for the size distribution and chemical composition of the particles in the tail of the comet if the particles are spherical or have large-volume shapes.

The possibility that elongated particles are dominant in the cometary dust is supported by some earlier measurements. Clarke (1971) showed that the plane of polarization for Comet Bennett 1970 II deviated significantly from one of the two possible orthogonal positions to the scattering plane. This effect can be explained by scattering on the aligned elongated particles. Harwit and Vanysek (1971) proposed the bombardment of dust particles by solar wind protons as efficient alignment mechanism. Because the rate at which the alignment occurs depends also on the gas flow from the nucleus, the polarization near the nucleus would be more arbitrarily oriented than in the tail where the solar wind predominates.

The elongated form of the particles can be expected if the crystalline formaldehyde polymers are present in the cometary dust. Vanysek and Wickramasinghe (1975) have recently discussed the possibility that the polymers $(H_2CO)_n$ are one form of formaldehyde in the comets. The polymerization process may produce polymer chains with variable length helically wound into a stable crystal. These particles would grow as long whiskers and possess optical properties in the visual and infrared region similar to those of the silicate grains.

5. PHOTOMETRIC PROFILES AND THE LIFETIME OF PARENT MOLECULES

The photometric profiles of the coma in monochromatic light are still used for the determination (or, better, estimates) of the lifetime of the parent molecules or precursors for the observed radicals, mainly CN and C_2.

The lifetime τ is defined as a reciprocal value of dissociation probability

$$\tau^{-1} = \int \sigma_\nu F_\nu \, d_\nu$$

where σ_ν is the photodissociation cross-section and the flux at a frequency ν is defined as $F_\nu = cu_\nu/h\nu$ where u_ν is the density of solar radiation (c = light speed, $h\nu$ = photon energy).

The value of σ_ν is about 10^{-18} to 10^{-17} cm^2 for the most common compound.

Results concerning the prospective parent molecules for cometary radicals (Potter and Del Duca, 1964) show that τ derived from the known cross-section and F_ν is for most compounds estimated longer than 10^5 seconds. These results, however, were not comparable with the scale-length for parent molecules determined from the polarimetric profiles of cometary heads.

The lifetimes derived from the early measurements on comets (a summary of these results is in Vanysek's paper [1972] in Nobel Symposium No. 21) suggest $\tau_p \sim 10^4$ sec. But the lifetimes determined for some components which could be possible parent molecules are $\tau_p = 10^{5.5}$ to $10^{6.5}$ seconds (except for NH_3 as a source of NH_2, with $\tau_p \sim 10^3$ sec).

The differences between laboratory and astronomical results were so striking that the hypothesis for the production of observed neutral molecules in comets via photo-decomposition processes was almost (but prematurely) abandoned and other theories were proposed (Wurm, 1961; Opik, 1963; Herzberg, 1964; Jackson and Donn, 1968).

The decomposition of parent molecules was ascribed to the predissociation or to the chemical reaction in the innermost part of the coma, or in the nucleus, or to the presence of free radicals in nuclei.

Delsemme and Swings (1954) considered that free radicals may be embedded in ice in the form of clathrates. This idea has been modified by Delsemme who assumed that small fragments of ice of submillimeter dimensions expelled from the nucleus into the surrounding halo contain considerable amounts of clathrate hydrates formed in the cavities in the water ice lattice where different molecules, even unsaturated, can be bounded by van der Waals forces. By a destruction of the lattice by solar radiation the encaged molecules are liberated into space and ejected isotropically from the cometary head. If the molecules are free radicals, or very short-lived precursors of such radicals, the ice particles play the role of parent molecules.

However, the problem of the precursors of the observed radicals is still the problem of the methods used. The lifetime of parent molecules τ_p and of the produced radicals τ_r can be estimated, in fact, only indirectly by determining $v_p\tau_p$ and $v_r\tau_r$ (where v_p and v_r are the expansion velocities, and supposed to be constant) from the intensity distribution in the cometary head. For the interpretation of the intensity distribution only a relatively simple model (Hazer, 1957) is usually applied in which the expansion velocity has no significant distribution.

However, the radiation energy absorbed by the molecule during the dissociation processes may be higher than the dissociation energy and may lead to a significant increase of the velocity distribution of dissociated compounds. For instance, if the difference between the absorbed energy and dissociation, $\Delta h\nu$, is only one or a few eV, then the velocity distribution $\pm\Delta v$ around the mean expansion velocity $\bar{v}_p$ for particles of molecular weight 20 may increase up to some km-sec^{-1}. Then a considerable number of the produced daughter molecules flow back into the "zone of production" up to some distance toward the nucleus where the collisions with expanding parent molecules and others increase above some critical limit. Only from this rough qualitative description does it seem to be evident that the simple coma model is invalid and the actual density of daughter molecules—radicals—should be considerably higher at distances, say 5×10^3 to 10^4 km, from the nucleus.

Moreover, recent results concerning the determination of lifetimes of the parent molecules from monochromatic isophotes with high angular (and consequently also spatial) resolution indicate that the scale-length $v_p\tau_p$ should be longer than 10^4 km (Rahe and Vanysek, 1974; Delsemme and Moreau, 1973; Kumar and Southall, 1974). Rahe and Vanysek found for the scale length of CN the parent molecule of Comet Bennett 1970 II $v_p\tau_p \simeq 5 \times 10^4$ km and about the same for C_2. For the virtually "dust-free" Comet Tago-Sato-Kosaka the results are: (CN) $v_p\tau_p \sim 8 \times 10^4$; (C_2) $v_p\tau_p \approx 4 \times 10^4$ km.

Kumar and Southall revised the isophotes of Comet Tago-Sato-Kosaka used by Rahe and Vanysek and applied a new correction of the sky background. The new results are: (CN) $v_p\tau_p = 1.7 \times 10^4$ km; (C_2) $v_p\tau_p = 2.5 \times 10^4$ km. (All values are for heliocentric distance $r = 1\,AU$.) The average value for $v_p \tau_p$ from recent results is equal to about 2 to 6 x 10^4 km, and if we assume the expansion velocity as derived from the radioastronomical detection of methyl cyanide $v_p = 0.4$ km sec^{-1}, then $\tau_p \sim 10^5$ sec $\sim$ 20 hours.

Most important results have very recently been obtained by Delsemme and Moreau (1973) from the spectra of Comet Bennett (1970 II) who determined the profile of the C_2 and CN bands from the distribution of brightness of the emission perpendicular to the spectrogram dispersion. It was proved that the scale-length of CN as well as of C_2 varied with r^2; the scale-length reduced to $r = 1\,AU$ was found to be 1.4 x 10^5 km for CN, and 0.9 x 10^5 km for C_2. The corresponding values for the parent particle scale-lengths are: (CN) $v_p \tau_p$ = 5 x 10^4 km and for C_2 = 2 x 10^4 km. Delsemme and Moreau noted that the scale-length for parent particles grew with increasing heliocentric distance r somewhat less rapidly than would be expected. However, the increase in geocentric distance was almost exactly the same as the increase in $v_p \tau_p$, and the effect of the variation of space resolution on the determination of parents' scale-length in this case must be taken into account. Moreover, these results may be affected by the kinematical behaviour of CN and C_2 molecules because the measurements provide profiles across the coma along the radius vector Sun-comet only.

Even if the solid hydrates of gases (clathrates) in icy grains are the source of some observed molecules in comets, the problem of other prospective parent molecules remains substantial; and there is no reason for excluding them as possible constituents in the cometary nuclei. One of the arguments for the "clathrate" model arises from the short lifetime of parent particles exposed to the solar radiation field. However, the scale-lengths of hypothetical precursors have been derived from the photometric profiles of cometary heads by an inaccurate method. Moreover, the expansion velocities of parent particles cannot be directly described and the real value of $v_p \tau_p$ remains highly uncertain and can easily be underestimated.

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