3 COMETARY DUST

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3.1 DUST IN COMETS AND INTERPLANETARY MATTER

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Summary: Results of many current attemps to estimate the physical and chemical composition of dust particles in comets are reviewed and discussed. It is shown that even the most basic parameters, such as albedo of the cometary dust, are not properly known at the present time. The emission feature in the infrared spectra of comets, which resembles those observed in the interstellar (and circumstellar) clouds and which indicates a relation between the general composition of comets and interstellar matter, is widely ascribed to silicates. Similar features may, however, be also caused by polymerized molecules or hydrocarbons mantles of the dust grains.

1. Introduction

The generally accepted concept that comets are the most efficient source of interplanetary dust, is based on the fact that the mass loss of the dusty material from a moderately bright comet during the perihelion passage at a heliocentric distance $r \leq 1$ AU is about 10^{13} to 10^{15} grams.

The physical properties of the cosmic dust in the cometary environment therefore constitute one of the relevant topics in the study of interplanetary matter.

The determination of the physical and chemical structure of dust particles in the zodiacal light, comets or interstellar space clouds is, however, one of the most difficult tasks in astrophysical research. Information on interplanetary dust based on the study of directly analysed samples is still very scarce and complicated by selection effects. Indirect methods used for the estimation of sizes and refractive indices of cosmic grains are based on the comparison of the observed and computed scattering properties of dust clouds likely to be found in interplanetary (or interstellar) space. Usually, the problems are restricted to the cases of spherical particles and to the use of some simplified assumptions about the size distribution function and the fitting of the computed models (based on the Mie theory) to the observational results.

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From this point of view, comets are very suitable as space scattering elements. The cometary head and tail are supposed to be optically thin media where the effects of higher-order scattering are negligible. The phase angle is perfectly defined by the position of the object in its orbit, and the integration along the line of sight involving the phase function can be neglected. The relatively large angular dimensions of the cometary head and tail permit surface photometry of the innermost regions of the coma and the kinematics of the tail provides some information on the dynamical effects of the light pressure on small particles which, of course, involves size and mass of the dust grains.

Light pressure and drag forces as well as the interaction of gas and dust (see for instance Finson and Probstein (1968), Shulman (1969), Sekanina and Miller (1973)), give rise to selection mechanisms separating grains with different sizes and optical properties from each other. But the most promising methods for the study of physical and chemical structure of the cometary dust are 1) direct analysis by space probes, 2) determination of optical properties of small particles including the search of emission or absorption at discrete wavelength intervals.

Only few samples of micrometeoroids which seem to be of cometary origin have until now been directly analysed by space probes (see Grün et al., 1976). The optical parameters of small particles studied by the colorimetry, spectrophotometry and infrared measurements are therefore practically the only sources of information about the grains structure. The limitation imposed upon this problem by comparing the observed properties of cosmic grains with those computed for particles of regular form (namely spheres and cylinders) constitutes, unfortunately, a disadvantage of this method. The Mie theory was successfully used in cases where almost identical particles have narrow-size distribution. In astrophysical objects, however, the variety of size and form of particles is large, and their distribution function, shape and chemical composition cannot be perfectly reproduced either by computed models or laboratory samples or both. Nevertheless, with the help of high-speed computers and idealized scatterers of the Mie theory, we may simulate some of the optical and physical characteristics of scattering aggregates impossible to reproduce in laboratory, but likely to exist in cosmic space. The same holds for the emission or absorption features of solids, particularly in the infrared region.

In the next paragraphs we review the present state of studies concerning the cometary dust by means of colorimetric, polarimetric and infrared observation.

2. Colorimetry

Earlier studies of cometary dust particle characteristics were based on the colorimetry or spectral gradients of the cometary continuum. The classical photometric system UBV is efficient for such a purpose only when the spectrum of the comet is a pure continuum. In fact we know only two such cases: Comets Baade 1954h and P/Schwassmann-Wachmann 1. Both objects were photometrically observed near the opposition with the Sun. The measurement of Comet 1954h made by Walker (1958) in the UBV colour system, indicates a definitely positive excess of about $+0.2^m$ in B-V (relative to the colour of the Sun), i.e. reddening of the scattered light. The same was found for several other comets (see Vanýsek, 1965). Although in other cases the influence of emission C_2-bands in the V-colour is evident, the tendency of "reddening" of the continuum seems to be typical of the bright comet, as well as of a very faint object (Johnson, 1960; Liller, 1970).

It is worth noting that the reddening of light scattered by interplanetary dust is a general phenomenon. Lillie (1972) concluded from the OAO-2 results that zodiacal light is redder than the Sun between 4300-2500 A, resembling a G8 V star. It is an obvious manifestation of the selective scattering of light. In UV below 2500 A the colour of zodiacal light is similar to the colour of B stars, and the albedo of the grains in this spectral region is relatively high. Similar behaviour of the continuum was observed in comets (see Lillie, 1976), but the albedo of the cometary dust is higher than that of the zodiacal cloud. From this point of view comets resemble the interstellar rather than the interplanetary matter. The spectrophotometric results of Comet Arend-Roland 1957 III show that the spectral distribution in the cometary continuum resembles the spectral distribution of G8 V stars and this is due to the selective scattering by small particles. Liller (1970), for instance, concluded that the scattering particles are iron-like conductive particles with diameters of about 0.3 microns. It can be shown, however, that dielectric particles fit the observation quite well provided that more precisely computed scattering properties are used.

The positive colour excess was confirmed recently by Babu and Saxena (1972) and by Vanýsek in an unpublished measurement of Comet Bennett

1970 II. Spectrophotometric results for Comets 1968 I, 1968 V and 1968 VI by Gebel (1970) show, on the other hand, that the reflected or scattered light is "grey" and the continuum energy distributions for these comets follow closely the spectrum of the Sun. Similar conclusions follow also from the measurements made by Johnson et al. (1971) in the continuum of Comet Bennett. These authors, however, used a very wide bandpass; contamination by molecular emissions may therefore significantly distort the assumed form of the continuum.

The discrepancy of the "grey" scattering results with the reddening deduced by other authors is not surprising at all. This may be merely an effect of the reflection of light by a bright central condensation where large particles dominate, in agreement with the colour change along the coma radius found in earlier colorimetric measurements by Vanýsek (1960).

Babu and Saxena (1972) (for Comet 1970 II) found a spectral gradient change with time; this may be caused by the dependence of light scattering on the phase angle or by time-changes in the dominant size or other physical characteristics of the dust particles. The results obtained by Babu (1975) for continuum energy distribution in the head of Comet 1973f indicate that the reddening of the scattered light decreases with phase angle and with heliocentric distance. These measurements were made at very large zenith distances, however, and the uncontrollable influence of anomalous extinction may alter the interpretation of the observed spectral gradients.

Theoretical values of the relative spectral gradient have been determined for different size distributions and different refractive indices for small particles for various models (Rémy-Battiau, 1966). The results show that the spectral gradient remains nearly constant for phase angles $90^{\circ} \leq \vartheta < 180^{\circ}$ ($\vartheta = 180^{\circ}$ is for the backward scattering) and is insensitive to the values of the physical parameters of the particles that have been considered. If $\vartheta = 30^{\circ}$ the spectral distribution of cometary spectra as well as the intensity of the continuum, are very sensitive to the phase angle. A considerable change in the spectral gradient can therefore be expected if the comet is observed near the inferior conjunction with the Sun where also a strong forward scattering effect may be expected. Similar significant changes can occur even at the phase angle $\vartheta \sim 90^{\circ}$ if the size distribution of the particles is very narrow.

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It seems to be very difficult to obtain reasonable conclusions from the colorimetric observations in the visual spectral range only. The usefulness of the relative spectral gradient Sun-comet (or colour difference Sun-comet) for the determination of the particle size is only limited by our virtual ignorance of the size distribution function. Another source of diffulties is the numerical modelling. Although in the computed models the integration of the intensity of the scattered light over a large grain size interval sweeps out some resonance peaks, and even if the process of the integration actually used modifies the phase only slightly, the differences of computed intensities in two or more wavelengths (which determine the computed colour) may be strongly affected by the accuracy of numerical results.
Nevertheless, precise spectrophotometry of the continuum in cometary spectra along the coma or tail would provide very valuable data. Such data can lead to inferences regarding possible differences between dust particles in the vicinity of the cometary nucleus and in distant regions of the tail.

3. Polarization

The radiation from comets is highly polarized. The polarization of the radiation from any particular object varies considerably with time, phase angle, measured area in the coma or tail and depends on the wavelength bandpass.

The polarization of the cometary light is caused by two mechanisms. One is the polarization of the fluorescence emission in the molecular bands and the other is the scattering of light by small dust particles. The linear polarization in the molecular band is about 8 % and is almost independent of the phase angle, while in scattered light polarization generally depends on the phase angle and may reach 50 %. Results reported by Michalsky (1975) for Comet Kohoutek 1973f were exceptional: the emission was more highly polarized than the continuum.

The presence of nonspherical dust particles in cometary atmospheres may cause circular polarization of the continuum radiation. No positive results have yet been obtained, however, i.e., no circular polarization larger than 0.05 % has so far been detected. Polarimetric measurements appear to be more efficient tools for the study of the physical properties of the dust component in comets than the colorimetric ones.

Just as has been the case with colorimetry, great care must be used when interpreting polarimetric results obtained from wide spectral bandpass photometry. The relative contribution of the continuum total flux in the bandpass used varies with time as well as with distance from the nucleus. The behaviour of the polarization of the large area measured is therefore not necessarily representative of the scattering properties of the cometary dust. The available polarimetric data on comets are still very scarce. Extensive sets of measurements were made for some bright comets (1957 III, 1957 V, 1970 II, 1973f) and a few fainter objects.

The polarization of the scattered light in the coma is, on the average, 15 to 25 % and sometimes increases up to 50-65 % near phase angles of 90° (although these extreme values seem to be unique to Comet Ikeya-Seki 1965 VIII). The measurements by Blackwell and Willstrop (1957) and Martel (1960) on Comets 1957 III and 1957 V indicate an increase in the degree of polarization from 5 % near phase angle $\vartheta \sim 145^{\circ}$ to 30 % for 90°. According to the result obtained by Gehrels (1972) the polarization of Comet 1970 II near $\vartheta \sim 90^{\circ}$ increases with the wavelength, ranging from 25 % at $\lambda \sim 0.5$ m to 41 % at 0.96 m. Very early studies of the dust characteristics of Comet Arend-Roland (1957 III) based on polarimetric data by Rémy-Battiau (1964) show that the presence of dielectric particles is more likely than that of metallic micrometeorites. A similar conclusion follows from the study of Donn et al. (1967).

Of particular interest is the change in the polarization vector from positive to negative, which means a change of orientation of the electric vector relative to the direction of incident beam (i.e. to the plane defined by Sun-observer-comet). In a study of the polarization on polydisperse cloud models (Vanýsek, 1971) it may be established that near the phase angle $\vartheta = 60^{\circ}$ the scattering by small particles exhibits a considerable increase in positive polarization with increasing particle conductivity. A high positive polarization (i.e. the electric vector perpendicular to the polarization plane is greater than the one parallel to it) is present for absorbing clouds (even with moderate absorbers) having a maximum between $\vartheta = 60^{\circ}$ to 90°, while on the other hand negative polarization near phase angles 150°-170° is very typical of all cloud models with dielectric particles. This, of course, is not valid for very small particles in the Rayleigh scattering domain. Variations in the polarization, which may help one to distinguish between dielectric and absorbing particles, are very pronounced near small or very large phase angles.

The sharp change of orientation of the polarization plane (orientation of the electric vector) with the phase angle is typical of the behaviour of a polydisperse thin cloud containing particles having a refractive index with a very small imaginary part. This polarization reversal is present in planetary atmospheres (including Earth) and has been observed in the zodiacal light (Weinberg, 1964; Wolstencroft and Rose, 1967; Weinberg and Mann, 1968; Frey, 1975).

From this point of view, the most important results concerning the polarization of cometary light are the ones from multicolour observations made by Weinberg (1974) for the tail of Comet Ikeya-Seki (1965 VIII). Data were obtained at six effective wavelengths and with two different filters centered at the 5577 A emission line of OI.

The measurements made along the tail axis provide information about the change of the degree of polarization with phase angle and neutral point (zero polarization). The phase angle of the neutral point is determined by the size of the particles and their refractive index, their alignment (in case of nonspherical particles) and quality of their surface, or by a combination of all these effects.

The negative polarization found by Weinberg and Beeson (1975) in the tail of Comet 1965 VIII, requires the presence of dielectric grains or that of highly irregularly-shaped particles. The interpretation is more difficult however, when elongated particles dominate the distribution of the cometary dust. Detailed measurements of the polarization made by Martel (1960) (Comets 1957 V and P/Giacobini-Zinner), Osherov (1970) and Clarke (1971) (Comet 1970 II) show that the plane of vibration (or the plane of polarization) sometimes deviates significantly from one of the two possible positions orthogonal to the scattering plane. Such a deviation may be caused by scattering by aligned and elongated particles. It has been shown by Harwit and Vanýsek (1971) that an efficient alignment mechanism might be provided by bombardment with solar wind protons. The extent to which particles become aligned depends also on the gas flow from the nucleus; the plane of polarization near the nucleus is therefore more arbitrarily oriented than in the tail, where the solar wind effect dominates. The polarization measurements of Comet Bennett made by Osherov as well as those by Clarke fitted very well this hypothesis. This means of course, that the models based on the Mie theory using spherical particles are inadequate for the estimation of the dust composition.

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4. Infrared Emission of the Cometary Dust

Infrared measurements constitute the decisive method for determining the physical characteristics of cometary grains. The interpretation of such data leeds to estimates of the albedo. The emission and absorption features in the infrared spectrum (outside possible Ballik-Ramsay C_2 emission wavelengths in near infrared) provide some information on the physical and chemical composition of the solid-state component of the cometary atmosphere.

Infrared measurements of the thermal emission from the dust component of the cometary atmosphere have been made for Comets Ikeya-Seki (1965 VIII); Bennett (1970 II); Kohoutek (1973f); Bradfield (1974b) and P/Encke (Becklin and Westphal, 1966; Maas et al., 1970; Kleinmann et al., 1971; Lee, 1972; Westphal, 1972; Rieke and Lee, 1974; Ney, 1974; Gatley et al., 1974; Merrill, 1974; Noguchi et al., 1974; Zeilik and Wright, 1974).

Most of these observations revealed emission features near 10 μm which had been widely ascribed to silicates. Similar features have been observed in infrared spectra of cool stars having circumstellar dust clouds.

By comparing the continuum radiation from the comet in the visual with that in the infrared regions, the optical albedo may be estimated. This can be done by assuming that the infrared emission consists predominantly in the reemission of the absorbed visible solar radiation. The infrared measurements made by Becklin and Westphal (Comet 1965 VIII) and Kleinmann et al. (Comets 1969 VIII and 1970 II) have in this manner been analyzed by O'Dell (1971). He estimated the particles' diameter to be about 0.1 micron and found a value for albedo of $\gamma = 0.3 \pm 0.15$. This method has recently been applied by Ney (1974) to Comets 1973f and 1974b. The albedo of the dust coma found in these objects was low ($\gamma = 0.18 \pm 0.2$) and results for Comet Bradfield 1974b reveal that the "silicate bump" has dissappeared and that the albedo decreases significantly in a few days because the dust in the coma must have changed from small to large particles. These values of albedo γ are, however, not identical with those determined from the ratio of the scattering efficiency Q_s to the extinction efficiency Q_e. If E_s is the measured specific intensity of the scattered light and E_r the radiation of the dust cloud, then for an optically thin case $E_r/E_s = (1-\gamma)/\gamma$ holds. E_s as well as E_r may approximately be defined by the Planckian maxima of the cometary visual continuum (colour temperature 5700 K) and infrared emission of the dust coma ($T \geq 300$ K, for heliocentric distances $r \lesssim 1$ AU). The scattered sunlight maximum depends only slightly on the selectivity of the scattering process, but the absolute value of E_s is a function of the phase angle. The submicron particles with a Mie parameter $x < 10$ and moderate absorption are the most efficient scatterers. For instance, a particle with the diameter of about one micron and the refractive index 1.7 - 0.05i at $\lambda \sim 0.5$ m has the ratio Q_s/Q_e 1:2; the albedo is then about 0.5. But the radiance of the particle at the phase angle $\vartheta = 90^\circ$ is only 10^{-1} of its radiance at $\vartheta = 30^\circ$ and about 10^{-5} of its radiance in the forward direction ($\vartheta = 0^\circ$).

For a dust cloud containing such particles one can find a high value for E_r/E_s (low albedo) if the phase angle is somewhere between $\vartheta = 30^\circ$ to 150°. Because of the prevalence of strong forward scattering, the value of γ increases up to 1 at $\vartheta = 0^\circ$. In the case of small reflecting (and slightly absorbing) particles a similar effect exists for backscattering angles. This phase effect could even be significant for clouds with a large variety of grain compositions and size distribution. The quantity is therefore some kind of phase albedo which is defined as $\gamma(\vartheta) = \Psi(\vartheta)\, Q_s/Q_e$ and in real cases $\Psi(\vartheta)$ is an unknown function. It is difficult to estimate the value of the true albedo but for phase angles $60 < \vartheta < 120^\circ$, is considerably smaller than the ratio Q_s/Q_e; $\gamma \leq 0.2$ obtained by Ney (1975) must be regarded as the lower limit of the grain albedo in the cometary atmosphere.

5. Grain Composition and Structure

From the preceding paragraphs it is obvious that knowledge of the physical structure as well as the chemical composition of dust particles in the cometary atmosphere is still fragmentary. A comparison of the available photometric and polarimetric data with results from the computed models of scattering media can lead only to uncertain conclusions regarding the absorptivity and approximate grain sizes. It seems that the submicron particles are more likely composed of low conductivity than of metallic-like material.

At small heliocentric distances even the less volatile grains vaporize and in the spectra of the Sun-grazing Comet 1965 VII, taken at a heliocentric distance $r = 0.14$ AU, many atomic emission lines, particularly of neutral Na, K, Fe, Ni, Cu have been observed (Preston, 1967; Spinrad, 1968). Relative abundances indicating a very low K/Na and a high Cu/Fe ratio have been found. Data on abundances are unfortunately, not quite representative of the light elements and cannot be used for a compilation of the "true" composition of dust grains. Dust particles are obviously carriers of sodium and are responsible for the appearance of the Na emission in the cometary tail far from the nucleus. Free neutral Na atoms have certainly short lifetimes until ionization and are unable to reach the observed distances from the nucleus. But the relative abudance of Na in the solids may be almost the same as in the cosmic mixture.

The emission peak near $\lambda \sim 10$ m and another one close to 20μm are, at the present time, the most interesting features in infrared spectra of comets and circumstellar dust clouds. They were attributed to metallic-silicate grains such as $MgSiO_3$ or similar compounds. On the other hand, there is no convincing evidence as to the existence of emission features near $\lambda = 1\,\mu$m; such emission might be expected from ferro-silicate material. Although silicate grains constitute an acceptable model for cometary dust, it cannot be ruled out that a considerable fraction of the submillimeter particles in comet atmospheres are polymerized molecules. Vanýsek and Wickramasinghe (1975) recently proposed polymerized formaldehyde for such a possible constituent. Formaldehyde polymers are expected to condense on silicate grains at temperatures ≤ 40 K. (Wickramasinghe, 1974, 1975). The polymerization reaction is exothermic with an exothermicity ~ 15 K cal mole^{-1} and is expected to occur spontaneously under interstellar conditions. The resulting polymer chains could be of variable length, and stabilized by the addition of monovalent atoms or ions. These chains are, in general, helically wound into crystal structures and are therefore endowed with considerable mechanical strength. The melting temperature depends on the degree of polymerization as well as on the nature of the end-groups in the chains; it is typically within the range of 450 - 500 K, or even somewhat higher. These particles grow as long whiskers and possess the optical properties required for interstellar and circumstellar grains.

Assuming that the polymerization hypothesis is correct, it must be concluded that a considerable amount of formaldehyde may be present in comets in the solid-state. It could also be a substantial reservoir of OH or CN radicals which serve to terminate the polymer chains, and which may be released when depolymerization occurs at high temperatures.

The optical properties of crystalline polymer $(CH_2O)_n$ (known as polyoxymethylene = POM) in the visible spectral range correspond closely with those of dielectric particles having a refractive index $n \simeq 1.5$; these are thus consistent with cometary data.

More important, however, is the 10 μm feature in infrared spectra. The absorption spectra of POM films show absorption bands in the range 8-12 μm. The strong optical activity in the 8-12 μm wavelength band and the variation of these bands with temperature could be important in explaining the behaviour of the 10 m-emission in cometary dust. The two principal bands at 9.2 μm and 10.7 μm are due to vibrational modes of bonds C - O - C in the polymer chains.

Formaldehyde in a solid-state polymer form may occur in large quantities even though its direct detection in comets appears most difficult. In the thermally radiating cometary dust the strongest emission bands of H_2CO are expected in region 8-12 μm, where, in fact, the most pronounced peak of infrared excess emission is observed. Unfortunately, an ambiguity arises because a similar feature is expected for thermal silicate emission. Likewise, the 3.4 μm band of Polyoxymethylene (which may be nearer 3.1 μm for $H(CH_2O)_nOH$) falls in the region of ice grain features. One possibility of distinguishing the emission of silicates from that of formaldehyde polymers is infrared measurement in the waveband $\sim$18-20 μm. There should be a stronger peak near 20 μm for silicate dust than for POM polymers.

Although no direct evidence for the presence of H_2CO in gaseous or polymer form in comets exists as yet, its presence should be considered probable in the cometary models. The stability of formaldehyde polymers, and particularly the high cosmic abudance of H, C and O compared with the abudance of Si, Mg and Fe suggests that formaldehyde polymer grains may be the major constituents not only of interstellar dust, but also of the outer regions of the circumstellar dense clouds, protostellar clouds, and also cometary matter. These grains originated from "starting" nuclei containing silicate or heavy elements.

Another constituent responsible for the emission feature at 10 μm waveband may be hydrocarbon molecules. The presence of CH bands in the visual cometary spectra provides evidence that saturated molecules as CH_4, C_2H_4, C_3H_4 ... C_4H_{10} can be expected in comets too. The possibility that the "silicate bump" observed in carbon stars is caused by hydrocarbons was recently discussed by Tarafdar and Wickramasinghe (1975). Most of these compounds have strong broad absorption (or emission) bands centred mainly at 11 μm. An infrared spectrum arising from mixture of hydrocarbon type C_nH_{n+2} will give a broad band centred at 9-11 μm. The source of a 10 μm feature in infrared spectra of cosmic dust clouds could either be the gas phase or it could be hydrocarbon mantles on solid particles, or both forms. Thus the

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"silicate bump" in the infrared spectra of comets is by no means conclusive for the presence of silicate-like particles in these objects.

It its worth noting that polymers are common in carbonaceous chondrites, and practically all carbon in such chondritic material is bound in the form of aromatic polymers with -OH and -COOH groups. Chondrites may also be typical ingredients of cometary meteoroids. Besides, in high-resolution spectra of bright meteors, bands of C_2 or CN are also observed (Ceplecha, 1971). Spectra photographed with the image orthicon technique show faint band structures in early parts of meteor trajectories (see Millman, 1976). Therefore, the presence of a high percentage of light elements H; C; N and O in meteoroids is highly probable.

The bulk densities of meteoritic particles, derived from meteor trajectories are very low, mostly below 1.5 g cm^{-3} with the lowest value 0.01 g cm^{-3}. These densities are considerably lower than would be appropriate for silicate material. Since the bulk density depends on the internal strength and porosity of the meteoric matter, a fairly "soft" binding of silicates and metallic grains with some kind of polymers cannot be ruled out.

In the central part of the cometary head, the presence of larger particles, probably having a rather complicated structure, must be expected. In an attempt to explain the discrepancy between the computed and observed life-time of the assumed parent molecules of observed radicals Delsemme and Miller (1970) developed a model. This model consists of clathrates of CH_4 in icy grains of diameter 0.1 to 1 mm in the halo of dusty material in the inner coma. The contribution of ice-like particles to the light scattering is significant in large heliocentric distances but becomes almost negligible at $r \lesssim 1$ AU.

The two-component or multicomponent characteristics of the solid-state compounds in cometary atmosphere are also suggested by the infrared measurements. Ney (1974) observed in Comets Kohoutek (1973f) and Bradfield (1974b) at least two different types of dusty material: One is characterized by "10 μm band" and somewhat higher albedo, the other with lower albedo and without emission features. The "10 μm" component may be ascribed to particles with higher albedo and having sizes smaller than $\sim 2\,\mu$m, the other may be ascribed to low albedo micrometeoroids with diameters of about $\gtrsim 20\,\mu$m. The brightness of the high-albedo cloud in visual and near infrared range is very high even if it represents a small fraction of all the solid state compounds produced by the nucleus.

The indirect methods applied to the determination of the cosmic dust characteristics provide only rough qualitative information on this problem. The dust components in comets have to be regarded as a mixture of particles with different sizes and compositions. Some particles may be relatively unstable. The light elements are more abundant in cometary solids than in the zodiacal light particles. The chemical composition and the physical structure of comets seems to be very similar to that of the circumstellar environment and the composition of grains may be identical. Cometary dust contributing to interplanetary light must evidently be depleted from light elements almost immediately after the release from the parent body. Only a direct analysis of dust samples collected "in situ" by space probes moving slowly along with the comet would be an irreplaceable method for a decisive analysis of the cometary grain composition.

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