15. PHYSICAL STUDY OF COMETS, MINOR PLANETS AND METEORITES (L'ETUDE PHYSIQUE DES COMETES, DES PETITES PLANETES ET DES METEORITES)

PRESIDENT: N.B. Richter VICE-PRESIDENT: B.D. Donn

ORGANIZING COMMITTEE: E. Anders, C.R. Chapman, A.H. Delsemme, O.V. Dobrovolsky, T. Gehrels, B.J. Levin, D.D. Morrison, J. Rahe, E. Roemer, A.A. Yavnel'.

I. INTRODUCTION

Comets, minor planets and meteorites provide us with valuable information about the past history of the solar system. They belong to the most primitive samples of the primordial solar nebula. Over the past years, we can record a considerable increase of interest in these bodies.

Sections II to IV of this Report were compiled and edited by the colleagues listed in each section. Due to the rather limited space allocated to our Commission Report, several contributions had to be shortened; a special effort was made to avoid duplication.

Besides IAU-Colloquium No.39: Relationships between Comets, Minor Planets and Meteorites (see also A.H. Delsemme, ed.: Comets, Asteroids, Meteorites; Univ. of Toledo, 1977), several other meetings and workshops devoted to the physical study of comets, minor planets and meteorites took place. In Dushanbe e.g., a colloquium on the "Physics of Minor Bodies of the Solar System" was held in August 1978. A few proceedings of meetings and books have been published. Most of the meetings and publications are mentioned in the following report.

The Cordoba "Cometas-Viento-Solar-Atlas" has been completed. Parts I (2nd ed.) and II of the "Isophotometric Atlas of Comets" (N. Richter, R. Högner) was published (German ed.: J.A. Barth; English ed.: Springer).

II. COMETS - J. RAHE

The following report was mainly compiled from contributions of the authors listed below. In addition, draft contributions were provided by Drs. Bappu, Bowell, Herzberg, Jackson, Konopleva, Mendis, Miller, Roemer, Sekanina, Shul'man, Sivaraman. The collaboration is gratefully acknowledged.

Since it was impossible to include in the report all publications that have appeared after the last General Assembly, it was attempted to present a critical review of the highlights of the main field of research during the past three years, illustrate the problems to be solved, and describe the plans for future research.

As was already done in the last report, the section on observations quoted without interpretations, has been omitted. Most of these observations can be found in "Astronomy and Astrophysics

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Abstracts", under "Comets: Listed Objects(103)" or "Minor Planets(098)".

As far as possible, the system of numbered references of "Astronomy and Astrophysics Abstracts" was used in order to save space.

1. Structure and Nature of the Cometary Nucleus - F.L.Whipple

The general conclusions concerning the cometary nucleus as reported in 1976 are supported by subsequent observations and analysis. Water ice still appears to be adequate for the volatile fraction of very short-period comets. For 10 comets with $q<1.5$ AU, Whipple (20.012.049) combines the measured non-gravitational forces with the magnitudes near aphelion to determine radii and albedos of the nuclei, assuming water ice as the volatile element. The results are self consistent. Half these comets show spotty (i.e. only partially active) surfaces. For younger comets of a single apparition, water ice is not volatile enough to produce the observed radial accelerations. However, from a statistical study of comet discoveries and durations Kresak (20.102.020) argues against a thin exceptionally volatile layer ("frosting") on the surface of new comets, suggested to be produced by cosmic rays by Donn (18.012.014) and by Whipple(20.012.049). On the other hand, strong support for highly volatile amorphous ice formed at very low temperatures in comets comes from laboratory work by Patashnick and Rupprecht (Final Rep. NAS 8-30566, Dudley Obs., 1977), supplemented by Smoluchowski's (20.012.049) discussion of amorphous ice formation in interstellar space. The laboratory experiments demonstrate surface chemical activity as well as phase changes in amorphous ices with temperature increases. Laboratory work by Dobrovolsky and Kajmakov (20.012.049), also indicates surface chemical activity and particle agglutination on the surface of sublimating contaminated H_2O ice. So we find another obstacle to the determination of the chemical and physical composition of comets from external observations.

From photometric data for more than 100 comets before and after perihelion Whipple (M&P,18, 343, 1978) finds that $\bar{n}$ in the r^{-n} law of brightness variation is statistically constant, 3.4, after perihelion for all comet classes with period $P>25$ yr. The Oort-Schmidt(51.8018) increase of $\bar{n}$ with increasing comet age arises from the pre-perihelion variation in $\bar{n}$ from 2.4 for new comets to ~ 5.0 for short-period comets. Whipple ascribes part of the effect to a purging of insulating crustal material near perihelion.

The long accepted idea that the spectra of new comets tend to exhibit a larger dust to gas ratio than those of old comets has been disproved by a statistical study of the observed ratio in 85 comets by Donn(20.012.049). High, medium and low ratios are comparable in frequency among comets of all age classes. Donn concludes that the spectral dust to gas ratio is a genetic property of a given comet depending on the grain size of the dust not the mass ratio. A less probable alternative is the existence of layers or pockets of different grain sizes in individual comets, for which there is also some evidence. In either case the data weaken the argument that old comets turn into near Earth asteroids. Perhaps Kresak's (B.A.I.C.,29,129,1978) strong evidence that the 1908 Tunguska event arose from an encounter with a piece of Encke's comet further weakens the case, in view of the lack of identification of any meteorites with cometary origin and the special character of Brownlee's (20.012.049) "cometary particles".

The phenomena of comet splitting have been immensely clarified by the orbital calculations of Sekanina (19.102.003; Icarus, 33, 173, 1978; 19.103.201; 20.012.049). In a massive study of the motions of the components of 14 split comets he finds that differential non-gravitational forces radial to the Sun provide good to excellent fit in relative motions in all cases. The components of split comets separate originally at extremely low velocities, at <1 to 2 m/sec, indicating a lack of significant explosive or ejection forces (rotation?). Sekanina finds a remarkable inverse log-log correlation between the non-gravitational force and the endurance or lifetime of a component, consistent with a fairly uniform volatility of split comet components independent of radius. The new Comet Wirtanen, 1957 VI, is calculated to have split at a solar distance of 9 AU with a relative velocity 26 cm/sec! In addition, Sekanina and Farrell (B.A.A.S., in press; A.J., in press) find that the breakups of comets West 1976 VI and Tago-Sato-Kosaka 1969 IX were accompanied by explosive events such as bursts of dust and brightness surges.

The rotation axes, sense of rotation and periods of rotation have now been determined for the nuclei of several older comets. From measures of asymmetric comas, Whipple (B.A.A.S., 9, 563, 1977) derives the polar axis and sense of rotation for P/Sch.-Wach. I, and Sekanina (Icarus, in press) for four short-period comets. In addition Sekanina determines the mean sublimation lag angles from the meridian, ranging from 0° to nearly 90°. The axes appear to be alligned more nearly with the orbital major axes than would be expected by chance. Basing their calculations on these results, Whipple and Sekanina (B.A.A.S. in press) find that the phenomenal variation in the non-gravitational acceleration for P/Encke can be explained by precession of the nuclear pole induced by the gyroscopic effect of the sublimation force on an oblate nucleus. The maximum polar motion may exceed 3° per period.

Fay and Wisniewski (Icarus, 34, 1, 1978), from a short photometric series, measure a rotation period of $5^{h}11$ for P/D'Arrest. Whipple (B.A.A.S., 9, 563, 1977) uses the coma expansion rates in outbursts of P/Sch.-Wach. 1 to determine a rotation period of 5.0 days. Similarly (Nature, 273, 134, 1978), from the halo diameters of C/Donati,1858 VI, he finds a period of 4.62 hours. For C/Coggia, 1874 III, he finds 9.1 hours; for P/Halley, 11.1 hr.; for C/Daniel, 1907 IV, 13.8 hr.; and for C/Swift-Tuttle, 1862 III, 33^{h} (NASA Tech. Memo. 79729, 32-34, 1978 and M&P in press) Whipple explains the outbursts from P/Sch.-Wach. 1 as arising from a thin insulating crust formed on the surface as it cools in the afternoon or night. When a small area of this crust is broken in sunlight, pieces falling back at 3-5 m/sec start a chain reaction of crustal breakage and exposure that results in an outburst. Thus the comet is physically unique only in mass. Comets Donati and Coggia are rare in that practically all the activity is limited to single specific areas.

2. The Coma - W.F. Huebner

Until a comet probe samples the nucleus, the composition of the nucleus must be inferred from analyses of coma observations. This realization, improved observational techniques, and plans for space missions to comets gave the impetus to determine production rates of cometary coma species observationally and to model the coma theoretically.

Reviews about the cometary coma or more general reviews about comets in which the coma receives much attention have been written by

Mendis and Ip (17.102.010) and Delsemme (18.102.044) about the neutral coma; Keller (SSR 18, 641) about the uv coma; Vanýsek (18.102.022) about coma photometry; and Delsemme (20.012.049), Arpigny (R.A. Welch Conf. Chemical Research XXI), and Whipple and Huebner (An.Rev.Astron.Ap. 14, 143) about physical processes. Based on observations and theoretical reasoning, it is generally accepted that a cometary atmoshere consists of an inner or molecular coma in which mother molecules dominate, followed by a radical or visible coma which gives rise to most of the observed molecular ions and radicals, and finally the atomic or uv coma which (at least for hydrogen) can reach out to several times 10^7 km. Dust pervades the inner and visible coma in most "new" comets coming straight from Oort's comet cloud.

On the other hand, labeling as mother molecules the only three stable molecules (H_2O, HCN and CH_3CN) detected to date, indicating that they exist as frozen gases in the nucleus, is a tempting generalization; it may only be true for H_2O. OH and H have been observed in uv spectra in several of the recent comets. The spectral intensities indicate that the two radicals exist in about equal proportions and show a marked onset during a comet's approach to the sun at a heliocentric distance (~1.4 AU) consistent with the expected onset of sublimation (vaporization) of water. The lifetime of the parent of OH (10^5 sec) is also consistent with that of water, but that value may not be unique to water. Oppenheimer (preprint) concludes that the brightness profiles of H_2O^+ and OH in comet Bennett (1970 II) are inconsistent with production of OH primarily by photodissociation of H_2O. Whether water is the dominant source of OH in all comets may have to await analysis of the recent radio detections of OH in comet Meier (1978f) by Crovisier et al.(IAU Circ.3226) starting at heliocentric distance ~2.6 AU (preperihelion); by Webber et al. (Workshop on Experiment. Approaches to Comet, Houston = WEAC) starting at greater than 2 AU and by Giguere et al. (WEAC) ~2AU. Water appears to be a major - i.e., conspicuous - constituent in most comets, but the often made assumption that it is the principal constituent - i.e., that the amount of water present is more than 50% of the frozen gases - may not be correct for all "new" comets (see also Biermann, Sitzungsber. Bayer. Akad. Wiss.)

The production rate of H to OH was determined by Keller and Lillie (AA 62, 143, 1978) in comet Tago-Sato-Kosaka (1969 IX) to be 3.3 to 1; possibly (but not definitely) consistent with water as the mother molecule. Remarkably, the H production rate at 1 AU postperihelion for the four comets Tago-Sato-Kosaka (1969 IX), Bennett (1970 II), Kohoutek (1973 XII) and West (1975n) is nearly the same, namely $(4.4 \pm 1) \times 10^{29}$/sec. Keller and Meier (18.102.019) developed a cometary hydrogen model that is useful for the interpretation of H-Lα observations. Opal and Carruthers (20.103.101;19.103.101) and Feldman and Brune (18.103.144) analysed uv observations of comets Kohoutek (1973 XII) and West (1975n) and related production rates of C and O relative to H and OH. They find that the H production rate is about four times that of O. Unfortunately they chose the lifetime of C ten times smaller than it actually is so that their C production rate is wrong. Feldman and Brune's conclusion that the parent of C must be CO is therefore questionable; they also assumed the lifetime of CO a factor of two too small.

Delsemme and Combi (ApJ. 209, L 149, 1978; ApJ., Feb.1979) revise the production rate of $O(^1D)$ in comet Bennett to 1.7×10^{29} s^{-1}; they explain it by the disssociation of 30 H_2O + 12 CO_2 (in 10^{28} molecules per second). Shimizu (Inst. Space and Aeronaut. Sc., Tokyo, 38) believes that $O(^1D)$ can be produced from OH dissociation in Lα-light. Wyckoff and Wehinger (17.103.102) obtained from the analysis of H_2O^+ spectra from comet Kohoutek (1973 XII) 10^{29} H_2O^+ ions within a radius of 10^4 km.

Biermann (Los Alamos Rep. 6289-MS) analysed unidentified lines from high-dispersion spectra of comet Mrkos (1957 V) and showed that with high probability many of these lines correspond to transitions originating from CO metastable triplet states. This requires large production rates of CO, most likely in excess of H_2O production. CO can be produced in its triplet states by dissociation of CO_2 and dissociative recombination of electrons with CO_2^+. Other molecules containing the CO group may also dissociate to produce CO in triplet states.

Vanýsek and Rahe (Moon and Planets 18, 441, 1978) interpreted the result $^{12}C/^{13}C \gtrsim 100$ from four comets - which is somewhat higher than the terrestrial ratio (89) - as a strong indication of a common origin for comets and the solar system.

Michel et al. (17.102.018) discuss the possibility of detecting H_2 emission in the near infrared from comets with large gas production and rich in CH_4.

The dependence of oblateness and size of isophotes as a function of gas production was modeled by Afanas'ev (17.102.016). Markovich (Komety Meteory, Dushanbe, 23, 12) has established the dependence between the generalized photometric parameter n(r) and the average temperature of the nucleus taking into account the heat of sublimation of the ices. Dryer et al. (18.102.063) suggest that comet brightness variations can be explained by the interaction of interplanetary shock waves with the coma. Miller (18.102.067) suggests brightness behavior is correlated to the general level of solar activity. Similarly Demenko and Demenko (18.103.105) correlate brightness variations with the daily sunspot areas on the solar disk. Sekanina (Icarus in press) relates deviations of anisotropic outgassing from the sunward direction with the spin of the nucleus. Going one step further, Whipple (Nature 273, 134) determines the rotation period of comet Donati (1858 VI) from its multiple halos to be $4.^h6$. Phenomenological similarities of the interaction of a neutral interstellar gas with the heliosphere and the interaction of the ionized solar wind with the neutral cometary coma have been pointed out by Wallis and Dryer (17.106.036).

Physical processes of comet Kohoutek (1973 XII) were described by O'Dell (18.103.123). This paper contains a thorough analysis of the observations. The total mass loss of the comet was 10^{14}g. Matsuura (17.102.019) attempts to obtain the conditions under which the production of dust in the coma is stationary under the action of solar radiation.

Limited modeling of the coma including chemical reactions has been carried out by Shimizu (17.102.015) on the temperature distribution and (17.102.017) on the ion distributions. Ip and Mendis (18.102.001; 19.102.001) modeled the cometary ionosphere for H_2O dominated comets and for CO rich comets. They conclude that photoionization and charge exchange processes cannot account for the observed column density profiles of H_2O^+ and CO^+. In order to obtain the required ion production rates they postulate a pinch current of the order of 10^8 to 10^9 A with 1 keV electrons that is generated in the ion tail and closes within a radius of 10^3 km around the nucleus. In their model calculations they simply assume that the lifetime of CO and H_2O before ionization is 5×10^3 sec; no cross sections or rate coefficients are calculated! Giguere and Huebner (Ap.J. 223, 638) have modeled the coma for 98 chemical species coupled in 441 photo and chemical reactions. Their calculations are based on time dependent chemical kinetics taking detailed uv optical depth into account. Starting with various combinations of H_2O, CO_2, NH_3 and CH_4 they cannot account for the abundances of many observed species. They suggest that other conventional processes not yet taken into account in the model such as ionization and dissociation by photo-electrons and ionization and dissociation from metastable states as well as different molecular species in the initial composition may bring about better agreement with observations.

Photochemical formation of cometary radicals has been outlined by Jackson (J. Photochem. 5, 107). This paper unfortunately contains photo-rate constants that are in disagreement with accepted values without providing any justification. Electron collision cross sections for several polyatomic molecules are given by Sushanin (18.102.004). The laboratory measurements of ion-molecule rate constants by Huntress (19.022.063) is of great importance to cometary modeling. It should be noted that there exists no definitive work on dissociation or ionization cross sections for the very important radical OH!

Dust is transported into the coma through entrainment by the radially expanding coma gases. Analytical approximations to this have been prepared by Michel and Nishimura in the limits of high and low gas production. Sekanina describes dust evolution from comets (Center Astrophys. Rep. 537). Ono (17.102.034) has analysed the optical properties of dust from observations of comets Kohoutek (1973 XII) and Bradfield (1974 III). The data extend over a wide wavelength range including polarimetric measurements in the optical and IR range.

3. Plasma Tails - J.C. Brandt

A full understanding of cometary plasma tails requires research in three distinct, but not independent areas: 1.) the dayside comet/solar wind interaction, hence, the processes responsible for the formation of plasma tails, 2.) the structure of already formed tails, and 3.) the interaction of the solar wind with fully developed tail systems. The years since the last report of Commission 15 have seen much progress in all three areas. Two excellent review articles on plasma tails and cometary ionospheres have been written by Mendis and Ip (20.102.025) and by Brandt and Mendis (1978, in Solar System Plasma Phys.).

a) Comet/Solar Wind Interaction

Most current work is an extension of two classic papers: those of Alfvén (57.8001) and of Biermann et al. (67.6707). Recently, Wallis and Dryer (17.106.036) have considered the flow regimes around a comet. These authors drew particular attention to the standing shock systems produced by the interaction with the solar wind. In addition to the contact surface and upstream bowshock predicted earlier, they also discussed downstream phenomena such as "barrell shocks", etc.

Delsemme and Combi (1978) extended their earlier study (Delsemme and Combi, 18.103.114) of H_2O^+ brightness profiles obtained near the head of comet Bennett 1969i. The recent study emphasizes wave motions seen in the antisunward direction, which may represent a periodicity in the production rate of H_2O^+, and the transition of the sunward

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profile from smooth to turbulent with increasing distance from the nucleus. The transition occurred inside of 10^5 km from the nucleus and may represent the first detection of the contact surface in a comet. The turbulence outside the contact surface would be expected as a result of the interaction of H_2O^+ with the shocked solar wind and chaotic interplanetary magnetic fields.

Miller (18.102.067) examined the correlation between the brightness outbursts of comets and disturbances in interplanetary space, namely, flare-induced shock phenomena. In a review of both past work and some new data, Miller concluded that no convincing correlation between a comet and a flare exists and that cometary brightness fluctuations are not presently effective solar wind probes. Hence, the cause of cometary flares remains a mystery.

b) Plasma Tail Structure

Ip and Mendis (18.102.007) consider the large scale structure of the plasma tail to be very similar to that of the geomagnetic tail. In their model, which is an extension of Alfvén's (57.8001) original idea, the capture of interplanetary fields produces a magnetic tube (or tail) composed of two oppositely polarized magnetic lobes separated by a neutral sheet in which cross-tail electric fields drive currents. The generation of these currents and electric fields is a natural consequence of the proximity of reversed magnetic fields on opposite sides of a neutral sheet. Disruption of the sheet via one of several current instabilities (e.g. ion-acoustic) could produce a current discharge through the inner coma and create the "internal" source of ionization which seems required by the limited production zone of molecular ions observed in short exposure photographs (also see Ip and Mendis 18.102.001; 19.102.001). Ip and Mendis also calculated the approximate magnetic field strength expected in the tail if magnetic flux conservation is valid and if the tail field is totally the result of captured interplanetary fields. They found that the field is considerably enhanced over that in interplanetary space: $B_t \gtrsim 100\gamma$. This value is in good agreement with the value derived by Hyder et al. (12.103.104) on the assumption that the helical structures observed in comet Kohoutek 1973f on 1974 January 13 were due to the classical kink instability.

Ershkovich (17.074.021) and Ershkovich and Heller (20.102.026) maintain that the helical structures observed in comets are due to the Kelvin-Helmholtz instability and that the magnetic field in a plasma tail is not enhanced relative to interplanetary fields. On the assumption that a plasma tail can be modelled as a plasma cylinder immersed in solar wind and separated from it by a tangential discontinuity, these authors derived dispersion equations for the growth of Kelvin-Helmholtz waves in the incompressible and compressible limits, respectively, and found that the phase velocity of Kelvin-Helmholtz waves is approximately equal to the speed of cometary plasma flowing down the tail. The identification of these waves with the observed helices is in agreement with observations if, as Ershkovich and Heller claim, the observed velocities of plasma tail formations represent bulk motions. From the observed amplitudes of helical structures and from considerations of pressure balance across the tail boundary, these authors derive a tail field strength which is approximately equal to that of the interplanetary field, in contrast to the results of Hyder et. al. (12.103.104) and of Ip and Mendis (18.102.007).

Morrison and Mendis (Ap.J.,1978) have suggested that fine structure in plasma tails, such as knots and wavy structures, could be

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produced by "resistive instabilities" which are known from laboratory experiments to disrupt current sheets separating reversed magnetic fields. The relevant current sheet in a plasma tail is that proposed by Ip and Mendis(14.103.102; 18.102.007) to divide the tail into two oppositely polarized lobes. Morrison and Mendis presented order of magnitude estimates of the instability criteria for the tearing and rippling mode instabilities using average values for plasma tail parameters, and concluded that the conditions for the onset of these current sheet instabilities can be met in a plasma tail. Knot-type features are suggested to result from the tearing mode and wavy structures from the rippling mode.

Lee (18.102.059) has re-examined the data of Ananthakrishnan et al. (14.141.094), who observed scintillations of an extragalactic radio source resulting from its occultation by the plasma tail of comet Kohoutek on 1974 January 5. Ananthakrishnan et al. pointed out that, while there was little doubt that the scintillations were caused by cometary plasma, it was difficult to understand the results within the framework of classical scintillation theory and the current understanding of plasma tails. The observing geometry and Ananthakrishnan et al.'s results seemed to imply that small scale density irregularities propagating <u>away</u> from the head of the comet could not have caused the scintillations. Ip and Mendis suggested that disruption of a cross-tail neutral sheet could produce currents closing through the coma, in other words <u>toward</u> the nucleus, and proposed this as the mechanism responsible for Ananthakrishnan et al.'s scintillation data. Lee suggested that Ananthakrishnan et al. incorrectly assumed that the scintillation was strong and used the wrong scintillation theory equations. He proposed that the observed scintillations can be understood as the result of an variation in the plasma tail electron density of $\Delta N = 80\ cm^{-3}$ and implied that the data do not require headward motion of the tail plasma. Lee and Wu (Ap.J., 1978) have attributed the strong density irregularities to the Kelvin-Helmholtz instability produced by a strong velocity shear between the cometary plasma flowing down the tail and the solar wind. Also in their model, the scattering of solar wind protons by the turbulent cometary plasma transfers momentum to the cometary ions, and can produce significant antisunward accelerations.

c) <u>Plasma Tail/Solar Wind Interaction</u>

The most well known response of a plasma tail to conditions in interplanetary space involves the solar-wind velocity field via the wind sock equation: $\underset{\sim}{t} = \underset{\sim}{w} - \underset{\sim}{V}$. The wind sock theory of comet tails has been discussed in detail by Brandt and Rothe (18.102.054). Belton, Brandt, and Niedner (1978) are currently preparing a supplement to the original catalogue of comet tail orientations of Belton and Brandt (66.9105). The average, long-term global velocity field resulting from the augmented sample is $w_r = 400\ km \cdot s^{-1}$, $w_\theta = 2.3 \cdot \sin 2b$, and $w_\phi = 6.7 \cdot \frac{(\cos b)^{2.315}}{r}$ (Brandt, Harrington and Niedner, 1978), where b is the solar latitude and r is heliocentric distance. The results compare very favorably with the earlier results of Brandt, Roosen and Harrington (08.074.067), and of Brandt, Harrington, and Roosen (10.106.014; 13.074.016).

Niedner, Rothe, and Brandt (Ap.J. <u>221</u>, 1014) investigated possible solar-wind causes of the large disturbance in the plasma tail of comet Kohoutek 1973f that occurred on 1974 January 20. The observing geometry was very favorable and <u>in situ</u> measurements of the solar wind were available for all time frames of interest. They attribute the distorted tail morphology to the comet's encounter with large and rapid changes in the polar component of the solar-wind bulk speed which occurred on the leading edge of a strong high-speed stream observed by the IMP 8 satellite. Supporting the temporal correlation was a strong resemblence between the observed and predicted variations of principal position angle. Ip (1978) noted that the ~0.5 day difference between the time of the tail disturbance and the corotated solar-wind feature possibly responsible for it may be due to the finite length of time required for a plasma tail to experience a change in the solar wind due to the ~0.5 d time scale for the folding of rays into the tail.

Niedner and Brandt (Ap.J. 223, 655) examined the phenomenon of plasma tail disconnection, which they first observed in comet Kohoutek on 1974 January 20, but later found by a literature search to be a common phenomenon. They attribute the tail disconnections to sector boundary traversals. The disconnection effect is understood as the result of the reconnection of oppositely polarized magnetic fields when the interplanetary fields incident on a comet past a sector boundary have opposite sign to those already captured from the previous sector. The reconnected fields are lost to the comet and a disconnected tail is the end result. The rapid release of stored magnetic energy is suggested by Niedner and Brandt to be a possible ionization mechanism in comets. Niedner (1978) is currently using an expanded list of disconnection events (DE's) to probe the three-dimensional structure of sector boundaries to high latitudes. Until the advent of the Solar Polar Mission in the 1980's, DE's may provide the only method by which interplanetary sector structure in three dimensions can be studied.

Ip and Mendis (Ap.J. 223, 671) have pointed out that the sector structure implied by the DE's discussed by Niedner and Brandt is not in agreement with modern theories of sector structure and suggest that it is a comet's interaction with enhanced solar-wind plasma density which disconnects the tail. They suggest that the correlations between DE's and corotated sector boundaries found by Niedner and Brandt are also correlations between DE's and high-speed stream compression regions, since sector boundaries are almost always situated on stream leading edges. Ip and Mendis attribute the disconnection phenomenon to the onset of the flute instability at the marginally stable contact surface, due to the sharp increase of solar-wind flux with the passage of a stream. Once triggered, the flute instability produces rapid mixing of cometary plasma, increasing the ionization rate, the result being a depleted neutral coma and a subsequent sharp drop in ionization, and ultimately, a disconnected tail.

The sector boundary model of plasma tail disconnection has been defended by Brandt and Niedner (1978), who show that several morphological aspects of the development and evolution of DE's follow naturally from the sector boundary model, but have no ready explanation under the compression picture. Moreover, these authors show that several DE's in comet Arend-Roland 1956h took place in the vicinity of magnetic polarity reversals, but not near high-speed streams.

The contribution of M.B. Niedner is gratefully acknowledged.

4. Dust Tails - V. Vanýsek

The isophotometry of dust tails may give some clues about the size distribution of dust particles in comets. The method based on the improved mechanical theory of cometary tails was applied by several authors (e.g., Sekanina, Miller, Kimura, Liu and others) and reviewed by Sekanina (Space Research, 17, 573, 1978). It must, however, be noted that the efficiency of this method seems to be somewhat overestimated since from the fitting of theoretical to measured isophotes, one obtaines for the particles only values of b, i.e. the ratio of the solar gravitational force to radiation pressure. Since b= const$\cdot Q_p/(da)$, where Q_p is the efficiency factor for the radiation pressure cross section of a particle with diameter a and density d, the conclusions about the product (da) are ambiguous.

In syndynames with low b, at least large particles with $a > 2\cdot10^{-5}$ cm, as well as small ones with $a < 4\cdot10^{-5}$ cm can exist since for non-absorbing particles, b has a maximum of about $3\cdot10^{-5}$ cm. Therefore only the combination of dynamical methods with other IR and polarization measurements can lead to the decision which kind of particles prevail for given syndynames. In fact, only for the antitail of Comet Kohoutek where the "silicate feature" in IR spectra was absent, the corresponding syndynames can probably be attributed to very large particles. However, similar conclusions about the presence of very large particles made by Sekanina and Schuster from measurements of the continuum distribution in the coma of P/Encke, should be taken with reservation.

5. Cometary Spectra - A.H. Delsemme

The anomalous intensity distribution in the Swan band of C_2 has been a puzzle for many years, although it was clear that it had to be explained by fluorescence. Danylewich et al. (Icarus 35, 112, 1978) still describe this anomaly by two different vibrational and rotational "temperatures" in the C_2 of 1973 XII and 1975 IX; they report column densities for C_2 but renounce to deduce production rates from the actual solar flux, apparently because they are puzzled by the non-Boltzmanian distribution. However, Kirshna Swamy and O'Dell (20.102.007) have now explained this peculiar distribution, by the excitation and cascading by fluorescence of the three triplet band systems of C_2, including the Ballik-Ramsay bands in infrared and the Fox-Herzberg bands in ultra-violet. The three triplet band systems interact, but are well isolated from other electronic states by the strong forbidding of the singlet-triplet transitions. A'Hearn (Ap.J. 219, 768) uses this interpretation and computes the complete triplet fluorescence equilibrium for C_2; a rotational Boltzmann temperature of 3000 $^{\circ}$K then explains easily the observations; the peculiar intensity distribution in the vibrational transition of the Swan bands are explained by spontaneous emission of the high vibrational levels of the lowest triplet electronic state of C_2 into the Ballik-Ramsay bands. In the absence of a pure rotation spectrum of C_2 to cool the molecule, the rotational "temperature" of 3000 $^{\circ}$K must therefore represent the steady state corresponding to the large but finite number of fluorescence cycles (a few thousands) that happen in the observable coma.

Three sounding rocket experiments on comet West (1976 VI), by groups from Johns Hopkins University, The University of Colorado and NASA Goddard Space Flight Center produced the first extensive spectra in the region 1200-3200 Å, that provided identification of CO, C^+, CS and S (Feldman and Brune, 18.103.144; Smith et al., 18.103.144). Resonance lines of atomic carbon and oxygen, first detected in Kohoutek (1973 XII) appear strongly in 1976 VI, as well as $C(^1D)$; dissociative recombination of CO^+ ions is proposed as an important source of $C(^1D)$; (Feldman, AA, 1978). Images of 1976 VI in Lyman α indicates optically

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thick behavior of the hydrogen envelope to large distances from the nucleus (Opal and Carruthers, 19.103.101; 20.103.101) and the derived H, O and OH production rate is consistent with an H_2O source. CO evolves at a rate about one-fifth that of water (Feldman, 1978).

The OAO-3 (Copernicus) has continued to make observations of Lyman in comets West, Kobayashi-Berger-Milon (1975 IX) and d'Arrest (1976 e); the high spectral resolution detects in the line profile two separate velocity components due to the sequential dissociation of H_2O and OH, and confirms the earlier analysis based on Lα isophotes of comets Bennett (1970 II) and Kohoutek (Drake et al., 18.103.123; Festou et al., Ap.J., 1978). C_2, C_3 and CN column densities or total abundances are also reported in 1973 XIII by Bouska et al. (20.103.701), Churyumov and Yurevich (20.103.702) and Neff et al. (17.103.102). Ferrin (20.103.461) interprets the CN(0,0) bands of 1957d through deactivation by collisions. A'Hearn (20.103.102) reports the dependence laws of C_2 and C_3 with heliocentric distance in 1975 n. Matveev and Chernova (Komety Meteory, 25, 11, 1976) do the same for CN(0,0) in 1970 II.

The first IUE spectra of a comet (1978m) were obtained by Jackson et al. (IAUC 3291, 1978) in the region 1200 - 3200 Å, several features (C,O,H,OH,CS,S,CO_2^+,CO^+,NH) could be identified, and the rotational structure of the OH(0,0) and (1,0) bands could be resolved.

Delsemme (20.102.038) uses molecular and atomic production rates of the last four bright comets, combined with dust-to-gas ratios, to construct a heuristic model of cometary H, C, N, O abundances in respect to Si. He finds that comet Bennett was 3 to 10 times less depleted in volatile (HCNO) molecules than C I chondrites, the most primitive meteorites. Arpigny (1978) studies the production rates of metals in the spectrum of sun-grazing Ikeya-Seki. He concludes that variations from solar abundances occur, which are not inconsitent with the vaporization pattern of refractory chondritic grains in the solar heat. Delsemme and Combi (Ap.J. 209, L 149; Ap.J. in press) have observed wave patterns in the spectral profiles of H_2O^+, moving at 17 km s^{-1} in the coma of Comet Bennett. A derived upper limit for the Alfvén velocity suggests total production rates of ions not larger than 3×10^{27} s^{-1}, inside a source of 10^4 km radius that they assimilate to the collisional zone of the coma. P. Feldman's contribution to this report is gratefully acknowledged.

Radio Spectroscopy - L.E. Snyder

To date seven comets, Kohoutek (1973f), Kobayashi-Berger-Milon (1975h), West (1975n), Bradfield (1978), Meier (1978f) and periodic Comets d'Arrest and Encke, have had detectable amounts of radio OH (Snyder et al.,18.103.144; Webber and Snyder, 19.103.603; Webber et al., 1977 B.A.A.S., 9, 564; Gerard et al., 20.012.049). Three comets, (1973f), (1975h) and (1975n), were observed to have OH emission and/or absorption lines which were in general agreement with the first-order model of ultraviolet pumping by the Sun which was initially proposed to explain the OH observations of (1973f) (Biraud et al., 12.103.104). In marked contrast, however, periodic Comet d'Arrest did not follow the predictions of the ultraviolet pumping model because the data show the 1665 MHz OH in emission and the 1667 MHz OH in absorption during a twelve day period immediately preceding perihelion. (Note: Comet Encke also displayed odd behavior).

With the exception of OH, most of the radio observations of

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Comet Kohoutek were consistent with the fluid dynamic model. Reasonable estimates for the success of future cometary searches can be obtained by starting from the expected production rate, possibly based on Comet Kohoutek results, and solving a fluid dynamic model to learn whether a projected density $N \geqslant 10^{12}$ cm^{-2} can be reached without excessive beam dilution. However, there are exceptions; e.g., we strongly suspect that the failure to detect 6cm formaldehyde in Comets Bennett (1969i) and Kohoutek (1973f) was due to inadequate excitation rather than an inadequate production rate. And, any prediction for OH must take pumping into account. At present, it appears that OH in young comets tends to obey the gross predictions of the ultraviolet pumping model but the OH in older, periodic Comets d'Arrest and Encke certainly did not. This perhaps may be because only a tiny fraction of the primordial volatile cometary material is still present and the densities and high temperatures resulting when this material finally is volatilized near perihelion passage may require infrared trapping to be added to the ultraviolet pumping model. Finally, OH velocities and lineshapes are found to be similar from comet to comet; this fact may greatly facilitate the identification of more complex molecular species in future comets.

Rahe et al. (20.103.105) report a negative result for two hyperfine transitions ($F = 1 \rightarrow 1$) and ($F = 0 \rightarrow 1$) at 9 cm of the ground state -doublet of CH in comet West (1975n). They obtained the rather low value of 1.1×10^{14} cm^{-2} as the upper limit for the column density assuming thermal excitation. A pumping mechanism similar to the one for OH should be investigated. Schloerb et al. (1978, Icarus in press) searched unsuccessfully for HCN, CO, and CH_3CN in Comet Bradfield (1978c). Their lack of detection of any of these parent molecules may have been due to a low gas production rate as compared to Comet Kohoutek (1973f).

6. Cometary Orbits - B.G. Marsden

Greatly improved statistical information on the distribution of "original" orbits of nearly-parabolic comets is provided by B.G. Marsden, Z. Sekanina and E. Everhart (A.J. 83, 64, 1978). This paper gives 110 new osculating orbits and "original" and "future" reciprocal semimajor axes for 200 orbits. The orbits are classified according to their accuracy and the possible influence of nongravitational forces is discussed. Inferences concerning the Oort cloud are mentioned, more particularly in the review by Marsden at IAU Colloquium No. 39 (20.102.044).

The reviews "Comets in 1974" and "Comets in 1975", by B. G. Marsden and E. Roemer, are contained in QJRAS 19, 38, 1978 and 19, 59, 1978, respectively.

The Minor Planet Center moved from the Cincinnati Observatory to the Smithsonian Astrophysical Observatory on 1978 July 1 and is operated under B. Marsden's direction. Although the Center is mainly concerned with positional observations and orbits and ephemerides, some interaction with those making physical observations is inevitable, and it is hoped that there will be more extensive contact in the future.

Several papers on dynamics-related physics of comets were included in the program of IAU Symposium No. 81, held in Tokyo in May 1978.

7. Origin of Comets - L. Biermann

The orbital data for 200 longperiod comets, for which precise (or very precise) original, osculating and future 1/a values have been derived, were compiled and rediscussed by Marsden, Sekanina and Everhart, A.J. 83, 64, 1978, who showed that they confirm again the existence of a reservoir of "new" comet (Oort's Cloud") with original aphelion distances of around 1/4 pc; the minority of apparently negative original 1/a values (outside the observational errors) derived from purely gravitational solutions (all of which pertain to comets with perihelium distances $\leqslant 2$) are judged to be caused mainly by non-gravitational forces, in line with the conclusions to be drawn from the observed absence of comets with strongly hyperbolic orbits (Sekanina, 17.102.002; Biermann, Proc. of Sympos. "Important Advances in 20th Century Astronomy", Copenhagen). The observed distribution of the 1/a values along does of course not unambiguously rule out the possibility that the origin of the cometary cloud was due to an encounter of the sun with a dense and cool interstellar cloud some million years ago (Yabushita and Hasegawa, MNRAS 183, 459, 1978, partially based on earlier work of McCrea, 14.131.197); such a cloud, however, at a required distance of only 10 pc by order of magnitude - both the formation and the capture of icy bodies require a slow collision (cf. Delsemme, 1977) - is not known, and the overall probability of such an event is of the order of one in some billion years or even less if more realistic densities ($\leqslant 10^4 cm^{-3}$) are considered (Talbot and Newman, 20.131.067; Biermann, 1978). That the comets are as old as the solar system is suggested by the isotopic composition of carbon, measured so far for five comets with at least some accuracy (Rahe and Vanýsek, Moon and Planets 18, 441, 1978).

The processes leading to the formation of cometary nuclei in the outer parts of a prestellar nebula (e.g. the presolar nebula) can be related, as was first realized by Cameron ("The Primitive Solar Accretion Disk and the Formation of the Planets", Center for Astrophys. Prepr. Ser. No. 666, 1977), to the gravitational instability of a disc of solid particles formed in the equatorial plane. Cameron showed that his model of the evolution of the presolar nebula (PSN) led in a natural way to the formation of such a disc, which, as shown by Goldreich and Ward (10.107.001) (for similar earlier work done in the Soviet Union see Safronov, 07.003.157) should become gravitationally unstable; the largest bodies formed by this instability would have the mass and chemical composition of cometary nuclei. In view of the fact that Cameron's models are difficult to relate to the theory of collapsing interstellar clouds (Black and Bodenheimer, 17.131.124; Biermann and Michel (Moon and Planets 18, 447, 1978) investigated the problem starting with the collapse of such a cloud; they proposed that plausible initial conditions lead first to a quasistationary state with approximate equilibrium between gravity, centrifugal acceleration and the pressure gradient lasting at least some 10 units of $(4\pi G\rho)^{-1}$, such that the larger solid particles would have time to sediment towards the equatorial plane (in the meantime work by Bodenheimer and Tscharnuter (MPI-PAE/Astro 155, 1978) has confirmed this conjecture in a general sense, though the relation to the special case of the PSN is not yet clear). Biermann and Michel then showed that the mass range of the solid bodies resulting from the gravitational instability of the disc thus formed depends only on the PSN's temperature and on the fraction of the total mass forming the disc, but not on its mass or angular momentum of rotation, and that the observed mass range of comets is recovered. The subsequent formation of Oort's cloud is then related

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to the loss of the unused parts of the PSN (during a stellar T Tauri phase) and to the influence of encounters with nearby stars.

In later papers it was shown (Biermann and Lüst, (Sitz. Ber. d. Bayer. Akad. d. Wiss., 1978; Biermann, 1978) that for limiting the size of Oort's cloud the influence of encounters with massive interstellar clouds should outweigh that of encounters with stars and that their effect is consistent with the aforementioned present value of the radius of Oort's cloud. The velocity distribution in it seems to be isotropic (Biermann, Sitz. Ber. der Bayer. Akad. d. Wiss., 1977; Biermann and Lüst, 1978) as had been suggested by Oort in 1950.

The distribution of the aphelia of "new" comets appears to be anisotropic (Hasegawa, 17.102.035; Biermann and Lüst, 1978), but the possible influence of observational selection has not yet been evaluated in sufficient detail to remove completely existing doubts concerning the magnitude of this anisotropy (Lüst, private communication, 1978).

8. Progress in Observational Techniques - V. Vanýsek

The photoelectric and polarimetric measurements in the narrow bands became more frequently used observational technique in the cometary studies in the past triennium. Most of the applied filters were almost identical with the recommended system for Standard Cometary Photometry (18.012.014, p. 3, tables 1 and 2). This system can be extended by some kind of red filter (Schott RG 1 or equivalent) in combination with a common photomultiplier or photoemulsions for isolation of the continuum flux near 0,56 μm.

Considerable progress can be noted in the exploitation of infrared photometry up to 20 μm chiefly for the determination of cometary dust properties. But there are unfortunately still some problems concerning the hetereogeneity of photometric data which are mainly due to the difference in passband half-widths of the individual observational sets.

Observations in the standard color system as well as in the narrow-pass band photometry data of brighter comets (particularly of Comet West 1975n) were obtained and interpreted by numerous authors in the past three years and are mentioned in various connections in other paragraphs in this Report. Therefore only few selected contributions are shortly summarized in this section.

Application of so called "strip" photometry is described by F.M. Strauss (19.031.220). This method gives useful informations simultaneously about the surface intensity distribution and total brightness of the coma. Color filter techniques for bright comets were discussed by C.F. Capen (17.012.021). Revision of monochromatic surface photographic photometry of comets Tago-Sato-Kosaka (1969IX) and Bennett (1970II) made by Rupprecht et al. (1978) shows, that improper reduction of the background intensities can lead to apparent life-times of the parent molecules which are longer than the true life-times.

The multicolor photometry extending from the visual to the far infrared region, became a very efficient tool for the study of the cometary dust. Comet West (1975n) has extensively been observed in the infrared region at several observatories in Japan. Photometrical and polarimetrical data were obtained in 12 spectral bands from 1.0 to

20 μm. The silicate feature near 10 μm is clearly seen and the polarization maximum in the spectral range 1.00 to 2.3 μm is about 30% near the scattering angle 90° (see Oishi et al.,20.103.106). The multicolor data obtained of the same comet by E.P. Ney and K.M. Merrill (18.103.144), covering the spectral region from 0.5 to 18 microns, clearly demonstrate that dust particles are strongly forward scattering, i.e. the phase function is typical for dielectric grains.

Absolute determination of the flux in the CN, C_3, C_2, and CO^+ bands, as well as the intensity distribution in the visual range of the continuum of Comet West 1975h were obtained at the Kavalar Observatory operated by the Indian Institute of Astrophysics, Bangalore.

As one of the very important tasks for observers, the accurate photometry of cometary nuclei should be recommended. Photoelectric studies of the nucleus of P/D'Arrest made by T.D. Fay and W. Wisniewski lead to the determination of periodic light variation and rotation of the entire body of the comet.

The photometry results obtained for several comets concerning the gas and dust production are studied by M.F. A´Hearn and R.L. Millis (BAAS 9, 507, 1977) who found remarkably small variations in the ratio of the production of CN and C_2. Further study of this problem, however, requires simultaneous monochromatic absolute measurements of the total flux and surface intensity distribution. Less accurate photometry or even estimate of the brightness of faint distant comets can still be a very valuable source of information.

The old photometric data of Bobrovnikoff and Beyer for more than 100 comets have been reanalyzed by F.D. Whipple for intrinsic brightness according r^{-n} law (BAAS 9, 507, 1977). New comets with P>25 yr approach perihelion with smaller values of n than old comets. After perihelion passage both classes of comets exhibit almost the same n value. The data enabling the study of light variation with heliocentric distances of faint distant comets would be crucial for a test of the hypothesis that volatile constituents prevail in the surface layers of "new" comets.

Extremly important data concerning the UV spectra of comet Seargent 1978m have been obtained by IUE satellite in the wavelength range 119.2 to 192.4 nm and 189.3 to 303.2 nm (IAU Circular No. 3291). These observations demonstrate that the IUE satellite can be used effetively to obtain high quality spectra of OH, CS, CO_2^+, NH, and CO^+ with resolution of 0.6 nm or 0.03 nm of comets as faint as 9th magnitude.

Searching for molecular species in comets by radioastronomical techniques have become an almost common program (see above). Many observations - especially those using satellites and radio techniques - would have been impossible without the continuous and efficient assistance by B.G. Marsden who provides the essential positional data and accurate ephemerides.

9. Laboratory Experiments on Cometary Material - B. Donn

This section emphasizes experimental results, other than spectroscopic, on cometary molecules and ices. Much useful material will be found in the Report of Commission 14. Attention is called to the three volume set dealing with diatomic molecules "Spectroscopic Data" ed. by S.N. Suchard and the revised edition of Pearse and Gaydon "Identification of Molecular Spectra", Halsted Press. Photochemical data appears in Okabe, "Photochemistry of Small Molecules",1978, Wiley Interscience, and Filseth, "Vapor Phase Photochemistry of Oxides and Sulfides of Carbon", Adv. in Photochem. 10, 1977.

A summary of experimental methods for reaction rates appears in McEwan and Phillips "Chemistry of the Atmosphere", Wiley and Sons. NY, 1976. A comprehensive list of rates for neutral species is contained in "Reaction Rates and Photochemical Data for Atmospheric Chemistry", 1977, ed. by Hampson and Garvin, National Bureau of Standards (US) Spec. Pub. 513, May 1978. A more specialized list is "Atmospheric Chemical Kinetic Data Survey", L.G. Anderson, Rev. Geophys. Space Phys. 14,151, 1976. Recent work on the reaction, $OH + CO \rightarrow CO_2 + H$ (Westenberg and de Haas, J. Chem. Phys. 58, 4061, 1973; Davis, Fischer and Schiff, ibid, 61, 2213, 1974) show that below 300 K, the activation energy is very low. The rate is independent of temperature and pressure (Burmann, Zetsch and Stuhl; 13th Informal Conf. on Photochemistry, 1978).

Many ion-molecule reaction rates have been measured by Huntress and associates and have been summarized by Huntress (19.022.063). References are given there to work by Fehsenfeld and Ferguson, Biondi, Schiff and others.

Laser spectroscopy by R.J. Cody of CN fragments from photodissociation of a number of parent molecules showed that the radical is produced in high rotational states and can be vibrationally or even electronically excited. Donn and Cody (Icarus 34, 436, 1978, where experimental references are given) showed that the excitation may be detectable in cometary spectra.

Jackson (J. Photochem. 5, 107, 1977) has proposed two photon sequential photodissociation for formation of NH from NH_3 and C_2 from C_2H_2. Other examples of how laser spectroscopy may be useful for cometary studies appear in the work of Jackson (Chem. Phys. Lett. 55, 254, 1978) and Houston and Moore (J. Chem. Phys. 65, 757, 1976).

ICES

Patashnik and Ruprecht are continuing measurements on the thermal behavior of ices. Rates of vaporization are given in Icarus (30,402,1978). They find that amorphous H_2O ice forms in mixtures with CO_2, NH_3, N_2 up to 50% impurity in some cases. Appreciable heat releases occur in the vicinity of the 140K transition temperature of pure H_2O ice. This material and previous work on the vapor pressure of ice and ice mixtures is being prepared for publication.

Theoretical consequences of the occurrences of amorphous ice have been examined by Smolochowsky (20.012.049) where references to experimentally determined properties are given.

Sputtering of water ice has been studied by Langerotti et al. (Phys. Rev. Lett. 9, 1978; Nature, 272, 431, 1978). They obtained a sputtering yield by MV protons about two orders of magnitude higher than calculations indicate and applied the result to erosion of icy grains in space.

A laboratory study of the effects of ice irradiation by energetic particles is underway at NASA/Goddard Space Flight Center. Donn is studying ice irradiation using 1 MV protons on films of various ice mixtures. An investigation of thermal properties and structure of condensed gas mixtures without irradiation has been initiated.

10. Cometary Missions - B. Donn and H. Fechtig

In 1977 a study group had been formed by NASA to investigate the possibilities to perform a rendezvous-mission to Comet Halley using low propulsion techniques. This so-called "Comet Halley Science Working Group" has compiled a report on the scientific merits and the performance of a mission to Halley (see report "A First Comet Mission", NASA, TM-78420).

Due to financial constraints the early launch of this mission could not be done. Therefore, the same group was asked to study a substitute mission. This so-called "Comet Science Working Group" (CSWG) has reported recently on an exciting mission to Comet Halley and Comet Temple 2 (see: "Reports to the Comet Science Working Group", July 1978, JPL and "A Strategy for the Space Exploration of Comets", July 1978, JPC).

According to these documents the CSWG recommends that the first comet mission be a rendezvous-mission to Comet Temple 2 and that this mission includes an en route flyby to Comet Halley in 1985.

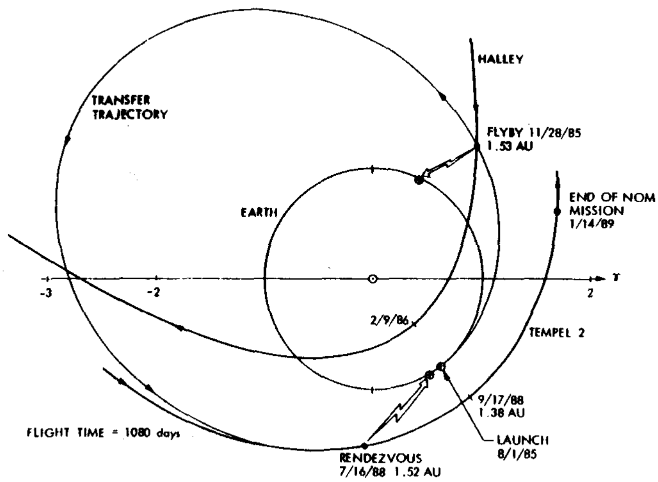

FIG. 1. HALLEY FLYBY/TEMPEL 2 RENDEZVOUS TYPICAL TRANSFER TRAJECTORY

The proposed trajectories, launch dates and distances from the Earth are shown in Fig. 1. The scientific objectives of this mission are:

- to explore the physical state and composition of the cometary nuclei,
- to explore the cometary atmospheres and dust envelopes,
- to explore the interaction of comets with the interplanetary medium and solar wind.

It is suggested to drop a probe for the Halley flythrough while the main spacecraft performs remote measurements during this phase. The strategy for the rendezvous is to approach the comet slowly (dust hazard) and finally land on the comet nucleus during a final phase of the mission.

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The payload includes imaging, mass spectrometers, dust analyzers, plasma analyzers, magnetometers, optical and IR spectrometers, radar- and radio sounder experiments etc.

A considerable scientific interest exists also in Europe. The European Space Agency has performed a Workshop on cometary missions (document SOL 78/14). It is hoped that the NASA-mission could be extended to an international mission by a possible participation of ESA or the Federal Republic of Germany.

11. Cometary Experiments in Space - J.M. Greenberg

In addition to the material contained in the Proceedings of the workshops mentioned above, the following cometary experiments in space are being planned:

H. Fechtig and his group are designing instrumentation to study the dust in the coma (Dalmann B.-K. et al.,"An Impact-Mass Spectrometer for In Situ Chemical Analysis of Cometary Particulates to be used on board a Flyby-Mission". Space Sc. Instr. 4, No. 1,1978).

A millimeter-wave radiometer, operating near 100 GH, is undergoing an engineering and science study for use on cometary rendez-vous mission (R.W. Hobba, J.C. Brandt,and S.P. Maran).

A high resolution ultraviolet spectrograph to be flown on the Space Telescope will be used to study physical processes in the cometary plasma and the possible detection of deuterium in Comet Halley (Principal Inv. J.C. Brandt).

T.R. McCord is working on the development of a reflectance spectroscopy experiment for spacecraft missions.

R.A. Lyttleton is investigating the danger from cometary particles to an intercepting space craft.

12. Cometary investigations in the USSR in 1976-1978 - O.V. Dobrovolsky

a) Monographs. A monograph by V.P. Konopleva, G.K. Nasarchuk,and L.M. Shul'man under the title "Surface photometry of Comets" was published in Kiew ("Naukova Dumka", 1977). It contains the methods of surface photometry with numerous auxiliary tables and examples, as well as the methods of the determination of the physical parameters of cometary atmospheres from surface brightness observations on the basis of theoretical models.

b) Discovery of new comets. Two new comets 1975e (Smirnova-Chernykh) and 1977l (Chernykh) were discovered at the Crimian Astrophysical Observatory (CrAO).

c) Photometry.V.G. Rijves (1) developed further and applied his original method of cometary photometry.

d) Polarimetry. The parameters of dust particles in the atmosphere of Comet Kohoutek were determined by L.A. Bugayenko et al. (2) on the basis of monochromatic polarisation measurements at different wavelengths as follows: radii $\gg 0.4$ km, refractory index $1.2-2.3i$. Dolginov and Mitrofanov (3) have explained the high polarisation degree and the anomalous orientations of the polarisation planes in comets as a result of scattering by elongated grains. Kiselev and Chernova (4) have discovered that dusty comas obey a polarisation-phase angle relation of the same shape as the one for asteroids, including the negative branch at small phase-angles. The same authors (5) observed a simultaneous change of color and polarisation degree during the development of some outbursts of Comet Schwassmann-Wachmann I and explained their observations as caused by gradual changing of the effective dimensions of dust particles in the coma. Kiselev and independently Osherov (6) made observations, which could be interpreted as evidence for a sporadic appearance of circular polarisation of cometary light.

e) Spectroscopy. Energy distribution in the continuum and in the emission bands of Comets Kohoutek 1973XII, Bennett 1970II and Mrkes 1957V are given in (7-10) on the basis of objective prism spectra. Absolute spectrophotometry of Kohoutek 1973XII using slit spectra (dispersion up to 50Å/mm) was made at CrAO (11) and at the Special Astrophysical Observatory (Zelenchuk) (12).

f) Radioastronomical observations. Observations of cosmic background observation at 12.6MHz in the Comet Kohoutek coma were discussed (13). Should the 1.6 times depression of antenna temperature observed on 14.1.1974 be real, the comets ionosphere would be much greater than suspected today.

g) Nucleus. Nuclear radii of Kohoutek 1973XII and Bennett 1970II were estimated as 5.5 and 6 km respectively (14,15). The rotation axis of the nucleus of Comet Brorsen-Metcalf 1847II was found to be inclined to the orbital plane at an angle of 45^{o} as shown by nongravitational effects (16). Dobrovolsky has found that the experimentally determined repulsive force is great enough to spin an evaporating non-symmetrical nucleus up to the critical value when the centrifugal disruption begins (CM, in press).

h) Coma. Dolginov's and Shul'man's isophote theories have often been applied. E.g., Afanasjev (17) has determined the speed of gas outflow from the circumnuclear zone for about ten comets and its dependence on the heliocentric distance r. The velocities v and lifetimes t of radicals CN,C_2,C_3 were determined (18) (typical values v = $33\cdot10^{5}$cm/sec, t = $3\cdot10^{4}$sec at r = 1 a.u.). There is a great number of determinations of the partial number densities of molecules, dust, and of brightness distributions in comas, including those from equidensitometry (see for instance (15), (19)).

i) Type I Tails. Vsekhsviatsky and Demenko (20) estimated the velocities and accelerations of ionized clouds in the tail of Comet Kohoutek 1973XII and compared them to the one observed in Comet Halley 1910II. Chernikov (21) has developed a detailed theory of cometary ion acceleration as a consequence of ion-acoustic instability.

j) Type II Tails. The dust ejection process in Comet Bennett 1970II has been investigated in (22). Between March 30 and April 9,1970, the effective acceleration $1+\mu$ had undergone appreciable changes. The greatest $1+\mu$ and correspondingly the smallest dust dimensions occurred on April 8-9 accompanied by a great dimension dispersion.

k) Interconnection between cometary and solar phenomena. The following connections were observed: CN, C_2 and C_3 band intensity in Kohoutek 1973XII during 22-30 January 1974 and solar flare total area (23); C_2 band intensity in Bennett 1970II and solar radiation at

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λ = 2cm (Mamadov, Dushanbe); light curve of Timmers 1946I and sunspot areas (24); comae dimensions and phase ϕ of the solar 11-year cycle (maximum at $\phi = 0.8-0.9$) (25). The disruption of cometary nuclei is found to occur more often during the maxima of solar activity (26).

1) Laboratory simulation. This has mostly been carried out at the Joffe Physical-Technical Institute (Leningrad), at the Institute of Astrophysics (Dushanbe), and at the Institute for Space Research (Moscow). Electron impact excitation of molecules of astrophysical interest has been studied in Uzgorod and Kharkov. Particularly the influence of minor organic compounds on visible cometary spectra was investigated (27); the water ice nucleus sublimation under electron bombardement and the properties of CO_2 nucleus were studied (Ibadinov and Khashimov, Dushanbe).

Interesting experiments simulating interaction between the solar plasma and cometary atmosphere were performed. It was shown that magnetized plasmas produce shock waves, whereas nonmagnetized ones do not(28).

References: (Abbreviations: C.C. - Cometary Circular (Kometnyj Tsirkular) Kiev; AC. - Astronomical Circular (Astronomicheskij Tsirkular) Moscow; AA - Astronomy and Astrophysics (Astronomia i Astrofisika) Kiev; P.S.Ph. - Problems of Space Physics (Problemy Kosmicheskoj Fiziki) Kiev; CM - Comets and Meteors (Komety i Meteory) Dushanbe). 1 - V.G.Rijves. Tartu obs.publ.44,151 (1976); 46 (1978). 2 - L.A. Bugaenko et al., C.C., N167, (1974). 3 - A.Z.Dolginov et al., Astron.Zh. 52,1268 (1975); 4 - N.N. Kiselev, G.P.Chernova, A C. N931 (1978); Astron.Zh.55,N3, (1978); 5 - N.N.Kiselev, G.P. Chernova, C.C.N223 (1978). 6 - R.S.Osherov, C.C.N184 (1975). 7 - E.B.Kostiakova, A A 29,81,(1976). 8 - Ju.V.Sizonenko, A A 29,87 (1976). 9 - Ju.V.Sizonenko and M.G. Sosonkin, A A 30,55,(1976). 10 - Ju.E.Migach and N.M.Shiper, PSPh. 11,122,(1976). 11 - N.F.Voikhonovskaya, V.S.Rylov, ibid.,11,97,(1976). 12 - V.P.Tarashchuk et al., A A 30,58,(1976). 13 - E.P.Abranin et al., Astron.Zh.55,123,(1978). 14 - V.P. Epishev et al., PSPh.11,100,(1976). 15 - T.N.Matveev, G.P.Chernova., CM N25,11,(1976). 16 - L.M.Belous, PSPh.12,110,(1976). 17 - V.L. Afanasjev, A A 29,76,(1976). 18 - K.I. Churyumov, F.I.Kravtsov, PSPh.11,126,(1976). 19 - O.V.Dobrovolsky et al., CM 25,11,(1976); 26,18,(1977). 20 - S.K. Vsekhsviatsky, A.A.Demenko, P.S.Ph.,11,111,(1976). 21 - Chernikov. Astron.Zh. 22 - L.F.Grigorjeva et al., PSPh.12,92,(1976). 23 - K.I.Churyumov, L.V.Jurevich, ibid.,12, 101,(1976). 24 - I.M. Demenko, A.A.Demenko, ibid.,11,108,(1976). 25 - O.V. Dobrovolsky et al., CM,25,31,(1976). 26 - V.A.Golubev, PSPh.11, 36,(1976). 27 - E.A.Kajmakov, I.N.Matveev, CM,26,9,(1977). 28 - I.M. Podgornij, Ju.V.Andrianov, Planetary and Space Sci.,26,99,(1978).

III. MINOR PLANETS - T. GEHRELS

A fundamental question about asteroids is "What are they made of?" Visible and near-infrared spectrophotometry, combined with spectral measurements further into the infrared, provide data pertinent to the major mineralogy of asteroids. Spectrophotometry in visible light for 200 asteroids has been published by Chapman, McCord, and their collaborators, or exists in unpublished form; at least 100 additional asteroids have been measured and the data are being reduced. Spectral types are C for carbonaceous, S for silicaceous, M for metallic, and

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E for enstatites. Spectrophotometry confirms the unusual nature of 785 Zwetana (and several other asteroids) suggested by broad-band data. Other spectra reveal surprising features, such as an absorption band for 434 Hungaria, which had previously been thought to be in the E class. While new spectral classes continue to be revealed, also by broad-band photometry, some of which may not have counterparts among the known meteorites, no clear examples of main belt asteroids with ordinary chondritic composition have been found.

Observational parameters for 523 asteroids have been assembled by Bowell et al. (1978a), and a taxonomic system for asteroids has been developed. There are five classes, defined in terms of seven parameters obtained from polarimetry, spectrophotometry, radiometry, and UBV photometry. Altogether, 190 asteroids are classified as type C, 141 as type S, 13 as type M, 3 as type E, and 3 as type R (red objects). Reliable diameters have been derived for 396 objects. Using a similar classification scheme and a smaller set of data, Zellner and Bowell (1977) examined the distributions of the various types as functions of semi-major axis and diameter, correcting appropriately for observational selection bias. Of the total main-belt population with diameters $>$50 km, 76% are of type C, 16% of type S, 5% M, and 3% other types. The S objects become progressively less common with distance, but are in the majority for a $\lesssim$ 2.4 a.u.

Recent work by Lebofsky and Rieke on Eros (1979) and by Lebofsky et al. (1979) on Amor and Apollo asteroids suggests on the basis of comparisons of UBV, polarimetry and radiometry that regoliths are not fully developed or are very thin at least for the Amors and Apollos (and also for small belt or "younger" asteroids). An on-going discussion concerns the interpretation of Ceres' spectrum. Broadband and narrowband photometry (3-4 μm) of 1 Ceres have revealed an absorption feature centered near 3.0 μm, which is the first evidence for water of hydration in the surface material of an asteroid (Lebofsky, 1978). A similar absorption feature has been observed on 2 Pallas and about 10 other C-type asteroids, but observations of S-type asteroids have yielded negative results. Selected asteroids down to the 14th magnitude (visual) will be observed in the future in the search for this absorption feature. The absorption seems to rule out earlier interpretations that Ceres might have a highly metamorphosed surface composition, perhaps similar to the C4 meteorite Karoonda. Besides ruling out C4's, Lebofsky believes that results based on visual and IR narrowband filter observations are consistent with the C2's. H. Larson et.al.(in preparation) interpret their own infrared spectrum, combined with the published visual data and Lebofsky's 3 μm data, as being entirely consistent with C2 meteorites. However, Gaffey (in preparation) believes the ultraviolet portion of Ceres' spectrum lacks certain charge-transfer absorptions present in C2 meteorites and he argues that Ceres has a hydrated, iron-poor, opaque-rich composition unlike any known meteorite.

Fourier transform spectroscopy continues to be an important technique for providing information on asteroid compositions (Larson and Fink, 1977) High- resolution IR spectra (0.8-2.5 μm) have now been obtained for 6 asteroids and each one poses a unique problem for interpretation. 349 Dembowska and 4 Vesta have spectra dominated by strong absorption bands of high-temperature silicates, and could have compositional links to the achondrite meteorites (Feierberg et al., 1978). 12 Victoria and 433 Eros have spectra consistent with mixtures of silicates and metal. 1 Ceres and 2 Pallas have linear,

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reddened spectra consistent with opaque-dominated mineral assemblages like those in carbonaceous chondrites (Larson et al.,in preparation). Observations will be continued on asteroids down to 10th magnitude (visual) and selected fainter ones of special interest.

Broad-band JHK photometry results are now available for 30 asteroids (Veeder et al., 1978). The data suggest that space weathering has not significantly affected the optical properties of the asteroids. High infrared reflectances of a number of asteroids strongly suggest the presence of a metallic phase.

The association between asteroids and meteorites has been addressed from an entirely different perspective by Housen et al., (1979) who have developed a model for the evolution of surface regoliths on small bodies such as asteroids. They have compared the predictions of the model with astronomical data (which do not seriously constrain regoliths) and with meteoritical data, especially concerning the gas-rich, brecciated meteorites. Such meteorites comprise between 2% and 100% of all major meteorite classes and are hypothesized to have been formed in small -body regoliths (see Anders, 1978, and references cited therein; Housen et al. 1979). The model of Housen et al., shows that asteroids may be expected to accumulate substantial regoliths in typical regions, primarily by the process of ejecta blanketing. The regoliths are poorly mixed and poorly gardened, in comparison with lunar soils. A number of features of gas-rich meteorites (radiation features, gas contents, petrographic textures, microcraters, etc.) are consistent with model regoliths for medium-sized asteroids. But the high proportions of gas-rich meteorites seem to require that multiple generations of surface regoliths are cycled through the asteroid interiors. Recent collisional modelling supports such an assumption.

Asteroid collision rates are higher than was thought a decade ago, primarily due to the revised diameter measurements. It had been hypothesized (e.g. by Chapman and Davis, 1975) that the asteroid size distribution might have evolved considerably, perhaps from a much larger original population. More recent analyses of energy partition in asteroid collisions suggest, instead, that most collisions result in substantial comminution and damage to the larger asteroids but that few collisions possess the energy sufficient to disperse collisional fragments from an asteroid's gravitational field. Thus fragments reassemble, producing an asteroid interior with a "megaregolith" character (Davis and Chapman, in preparation).

Wetherill (personal communication) argues that the most frequent collisions are too small to totally fragment the asteroids, but instead produce craters, and even for the larger asteroids a small but non-zero fraction of the crater ejecta from most collisions will exceed the escape velocity. The ratio of impact energy to fractured mass will be less for disruptive collisions and the kinetic energy available for escape will be smaller. As a consequence the yield of escaped fragments may primarily come from cratering events. In Wetherill's opinion the importance of cratering has been underestimated in most discussions of this problem. While the collisional lifetime of asteroids may be primarily controlled by catastrophic collisions, the total mass of escaped fragments does not result primarily from catastrophic collisions.

Lightcurve observations have been made by Debehogne et al., (1977, 1978a, 1978b), Degewij (1978), Degewij and Zellner (1978), Dunlap and Taylor (1979), Gehrels and Taylor (1977), Gradie (1976), Lagerkvist

(1977, 1978, 1979), Lagerkvist and Pettersson (1978), Lustig (1977), Lustig and Hahn (1976), Scaltriti and Zappalà(1977a, 1977b, 1977c, 1978), Scaltriti et al. (1978),Schober (1976a, 1976b, 1978a, 1978 b), Schober et al. (1977), Surdej and Surdej (1977, 1978), Taylor (1977, 1978), Taylor et al. (1976), Tedesco (1979), Tedesco et al. (1978), van Houten-Groeneveld et al. (1978), and by Zappalà et al. (1978). These results, together with all known past photometric data have been collected by Tedesco for the TRIAD ("Tucson Revised Index of Asteroid Data") file.

Harris and Burns (1979) and Tedesco and Zappalà(in preparation) have analyzed the lightcurve data in a study of collisional processes. Their results are in general agreement. The long-held belief that smaller asteroids spin more rapidly than larger ones is primarily a selection effect. Smaller asteroids appear to be more irregularly shaped than larger ones (at least down to diameters of $\sim$10 km). Degewij's (1978) photographic study of 96 small (1-10km) asteroids shows that these display relatively small lightcurve amplitudes. Harris (1979) finds that numerous small collisions prevent all except the smallest asteroids from being spun up. Asteroid spin rates seem to depend on taxonomic type with C asteroids spinning only about 80% as rapidly as non-C members. The mean densities of C-class and non-C-class asteroids have a ratio of 2:3.

Bowell (1977) draws somewhat different statistical inferences from his UBV survey. Histograms of brightness variation that can be ascribed to axial rotation show no difference between C and S asteroids. Thus one type is not, on the average, more or less spherical than the other. When brightness variations are broken down as a function of diameter, only a weak dependence is apparent for objects larger than 50 km in diameter. Therefore, small asteroids are not markedly less spherical than large ones, in agreement with Degewij's (1978) study of 1-to-10-km-diameter asteroids, but conflicting with Harris and Burns' (1979) study of larger asteroids.

Besides observations of asteroid rotations and size distributions, perhaps the most direct observations pertaining to asteroid collisional evolution are those of physical properties of Hirayama family members. Tedesco (1979) studies the shapes and spin rates of asteroids belonging to the first 9 Hirayama families; the results are consistent with the collisional origin for these families, with the possible exception of the Phocaea and four Flora families. Measurements of color and albedo for members of the large Eos and Koronis families (Gradie, 1978) demonstrate that the precursor bodies were of relatively homogeneous composition, but different from other asteroids at similar semi-major axes. Still other families exhibit compositional heterogeneity. Whether such heterogeneous families can be interpreted in terms of the collisional fragmentation of a geochemically plausible precursor is still uncertain (Zellner et al.,1977). Application of the TRIAD file to the families defined by J. G. Williams (in preparation) should make a major advance in understanding collisional and geochemical processes in the asteroid belt.

Interpretations of asteroid spectra in terms of mineral assemblages have led to a consensus that the major asteroid mineral assemblages are similar to those of many meteorites. For some of the Apollo-Amor asteroids that have ordinary chondrite-like spectra some researchers (e.g. Anders, 1978) speculate that the common S-type asteroids are, in fact, ordinary chondrites. But Veeder et al. (1978) interpret their

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1.6 and 2.2 μm photometry as confirming Gaffey and McCord's (1977) interpretation of S asteroids as being more metal-rich than ordinary chondrites.

There are continuing advances being made in understanding dynamical processes by which asteroid fragments may be delivered to Earth as meteorites. Wetherill and Williams (1978) have concluded that the combined effects of secular, Mars, and Earth perturbations on such fragments from low-inclination inner-belt asteroids could provide an adequate source for the stony and metallic differentiated meteorites. Wetherill has recently suggested that such inner-belt asteroids may not all have originated in the asteroid belt; some may have formed near the Earth and subsequently have been "implanted" into the asteroid belt (Wetherill, 1977). Wetherill (1976), Levin et al., (1976) and Levin (1977) have reinvestigated from a dynamic point of view the possible role of Apollo and Amor objects as sources of chondritic meteorites. Estimated mass yields are found to be in agreement with observations. However, whether or not it is possible to match the observed meteorite radiant and time-of-fall distributions to those predicted for this source remains uncertain. Wetherill (1979) has calculated steady-state orbital distributions expected for Apollo-Amor objects derived from hypothetical cometary and asteroidal sources. It is found that these distributions are not strongly source-dependent, and are similar to those observed. This work, as well as that of Neukum et al. (1975), Shoemaker (1977) and Grieve and Dence (in preparation), shows that the crater density on the earth and moon agree within a factor of about 2 with that expected by impacts of Apollo objects. However, relative to the moon the observed terrestrial cratering rate appears too high by a factor of 1.5 to 3. This could indicate an increase in the number of Apollo objects during the last $\sim$ 600 my, but other interpretations are possible.

Shoemaker and Helin are continuing to search for Mars-crossing and Earth-crossing asteroids, using the 46-cm Palomar Schmidt telescope. Five Apollo-type asteroids have so far been found, including three with semi-major axes $<$1 a.u. The high proportion of these latter objects implies a considerable population of these asteroids.

Kowal is conducting a systematic survey of the outer parts of the solar system, using the 122-cm Palomar Schmidt telescope. The main result of this survey has been the discovery of (2060) Chiron ($\equiv$ 1977 UB) which is an object between the orbits of Saturn and Uranus. In addition one new Apollo asteroid was found, (1977 HB), and the lost asteroid Adonis was recovered.

Another survey of Trojans of the earth (see Gehrels 1977) failed to yield any down to the 19th magnitude.

1 Ceres, 2 Pallas and 4 Vesta do not occupy a specific position in the mass distribution of the asteroids (Kresák 1977). The size distribution of the largest asteroids within the main belt and within the asteroid families does not reveal statistically significant deviations from a continuous model distribution that is consistent with collisional fragmentation.

Magnitudes and color indices for about 550 asteroids have been measured to date by Bowell in a UBV survey of asteroids. Some statistical inferences have already been drawn. Bowell (1977) finds that mean phase coefficients depend on geometric albedo. For C types β_B = 0.0382 mag/deg and for S, 0.0280 mag/deg. Both values are larger than the currently used value of 0.023 mag/deg. Tedesco (1979) has additionally noted a dependence of the phase coefficient on diameter. Lumme and Bowell (1979a,b) have developed theories of single and multiple scattering in rough and porous surfaces that model the phase functions of all atmosphereless solar system objects with a single free parameter. The opposition effect, the dependence of phase coefficient on albedo, reddening with phase, and limb darkening are all correctly predicted by the theory.

UBV photometry has also been continued by Degewij et al. (1978). An eight-color photometric system is being initiated by Gradie et al. (1978). A listing of magnitudes for all numbered asteroids was compiled by Gehrels and Gehrels (1978). Gehrels and Tedesco (in preparation) compile the magnitudes again, for TRIAD, but now with phase coefficient 0.035 mag/deg instead of 0.023. Polarization measurements during a lightcurve cycle were made on 1 Ceres and 4 Vesta by Degewij and Zellner (1978). Ceres remains constant to within one part in 200 (i.e., $\pm$0.01/2%) polarization, on the average, during a rotation cycle, while the polarization of Vesta varies by 10 per cent (i.e., $\pm$0.05/0.5%). The rotational brightness variation of Vesta is therefore explained with spots of various reflectivity over its surface. The spots may be due to discrete differences in composition, or to partial excavation to deeper layers by meteoritic impact. In general, however, the surfaces of asteroids are quite uniform.

Speckle interferometry (Worden et al. 1977) is beginning to be applied to asteroids. The size of Pallas has been directly measured by observing a stellar occultation from seven sites. Wasserman et al. (1979) find Pallas' mean diameter to be 538 $\pm$ 12km, implying a mean density of 2.8 $\pm$ 0.5 g$\cdot$cm^{-3}. This is the most accurate asteroid diameter yet derived. From observations of a stellar occultation by 532 Herculina, Bowell et al. (1978b) derive a mean diameter of 217 km for that asteroid. A secondary occultation, observed from two widely separated sites, is tentatively interpreted as being due to the presence of a 46-km-diameter satellite of Herculina, at a projected center-to-center distance of 977 km. Van Flandern (1978) recalls from existing literature various reports regarding binary asteroids and possible satellites of asteroids and he concludes that such satellites and binaries must be occurring frequently. Tedesco (1979) also finds evidence of binaries, namely among the larger members of the Themis family. Hartmann and Cruikshank (1978) describe Trojan asteroid 624 Hektor as a partially coalesced pair of planetesimals, the result of a collision midway between cratering and catastrophic fragmentation.

Recent reviews of the asteroids have been published by Chapman, Williams, and Hartmann (1978) and by Chapman (1978).

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IV. METEORITES

Studies of meteorites carried out in the USSR - A. Yavnel, B. Levin

Tracks from primitive irradiation by low-energy iron-group nuclei of solar cosmic rays are found in silicate inclusions from iron meteorite Elga and stone meteorite Weston (Kashkarov et al., 1975; Lavrukhina et al., 1977). A hypothesis is put forward on different mechanisms of capture by meteoritic matter of the two types of primary noble gases: type A - Thermal impregnation during the cooling of silicate dust-particles in the protoplanetary cloud; type B - intrusion of solar wind ions into the crystalline lattice (Levskij, 1976). A Ca- Al- rich inclusion from the Allende meteorite is found to be depleted in primary noble gases as compared with the bulk of the meteorite. This indicates the secondary character of the inclusion (Levskij, 1977.) A division of meteorite parent bodies into primordial, intermediate and last ones is proposed (Levin, Simonenko, 1977). From the determination of the atmospheric trajectory, radiant and orbit of the Farmington meteorite some conclusions about main stages of its history, as fragment of an Apollo asteroid, are proposed (Anders, Levin, Simonenko, 17.105.101,). In a course of a study of magnetic properties of carbonaceous chondrites their rather homogeneous magnetization, dependence between I_n and $\varkappa$ and the presence of stable magnetization are established. An estimate of magnetic field (1-2 oe) that produced the magnetization of these meteorites is obtained (Gus'kova, 17.105.111, 1978). The cosmic abundance in carbonaceous chondrites is obtained taking into account its addition from the atmosphere (Stakheev et al., 1975). From abundaces of non-volatile and volatile elements it was shown that carbonaceous chondrites can be divided into two main groups: 1) CI, CII, CIII-V, and 2) CIII-O (Yavnel', 14.105.068; Yavnel' et al., 17.105.106). By Mössbauer spectroscopy it was shown that at heating of carbonaceous chondrites the dehydratation of their serpentin minerals occurres at 550-750^{o} C and that at 850^{o}C they transform into olivin (Malysheva et al., 1977). It is shown that the content ratios of noble metals in the metallic phase to that in silicate phase of unequilibrated chondrites of H and L types is on the average smaller than in equilibrated ones. Prior's rule for these elements correct only for equilibrated chondrites (Vinogradov et al., 1972, 1973 ; Yavnel', 1977). The Mg, Fe, Si, Ni and Co distribution between glass and skeleton crystalls of olivin from chondrites was studied by electron-probe. It has been shown that fractional crystallisation of meteorite matter connected with shock-effects, occurred with a lack of equilibrium

(Yasinskaya, 18.105.113). By electron-probe analysis it was established that in zoned taenite from chondrites, as well as from iron meteorites, the cobalt concentration profiles have W-shape. This is compatible with a suggestion of similar formation process of kamacite and taenite in both meteorite classes (Yavnel' et al., 1977). By microscopic study of olivin crystals from pallasites it has been found that capillar inclusions are situated along crystallographic directions (Perelygin et al., 1976). The difference of correlation characteristics of some elements with nickel is shown for: 1) the chemical groups of iron meteorites; 2) the meteorites in these groups and 3) the nickel-iron phases in individual meteorites. This is an evidence of different mechanisms of chemical fractionation during the distinct evolution stages of meteoritic matter (Yavnel', 1977). The chemical and mineralogical composition and structure was studied for above 20 stones and irons (D'yakonova, Kharitonova, Kolesov, Yudin, Semenenko, Kvasha, Kirova, Skripnik,and others, 1976-1978). A spectral and neutron-activation analysis was applied to study silicate spherules (Kolesnikov et al., 19.105.022), peat (Alekseeva et al., 18.105.132; Golenetskij et al.,1977) and soil (Zhuravlev, Demin, 19.105.023) from the area of Tunguska event. An increased content of volatiles was found, compatible with a cometary nature of the Tunguska meteoric body.

Meteorites - L.L. Wilkening

One of the basic reference works in the field of meteoritics, the British Museum's Catalog of Meteorites,was updated by the publication of An Appendix to the Catalogue of Meteorites by Hutchison, Bevan and Hall in 1977. Newly recovered meteorites are described in the "Meteoritical Bulletin" which is now published in Meteoritics. Published reviews include a review by Stacey on the paleomagnetism of meteorites (Ann. Rev. of Earth and Planetary Science, in 1976), Clayton's review of isotopic anomalies (Ann. Rev. Nucl. Sci., 1978), Wilkening's review of carbonaceous material in the solar system (ZN 65, 73).

The availability of meteoritic material increased drastically after the recovery of large numbers of meteorites from Antarctic ice sheets by Japanese expeditions and a joint American-Japanese team in the Transantarctic Range. It appears that two new meteorite types have been discovered among the relatively small fraction of Antarctic meteorites which have been studied.

The recovery and study of interplanetary dust from the stratosphere (e.g., Brownlee et al., LSC 8, 149) and meteoritic spherules recovered from deep-sea sediments (Brownlee et al., LPS IX, 126) have provided new materials yielding different types of information on extraterrestrial debris. The structure of interplanetary dust shows that it was never part of any known type of meteoritic object, although the chemical compositions are very similar to known meteorites , especially to carbonaceous chondrites.

Since the discovery by Clayton and co-workers in 1973 of non-solar system (exotic) oxygen isotopic compositions in refractory mineral assemblages (CAI's) which occur in carbonaceous chondrites of types C2 and C3, the search for exotic isotopic compositions (anomalies) has been extended to several other elements. Isotopically anomalous compositions have been reported in CAI's for: Mg (Wasserburg et al., GRL 4, 299), Si (Yeh and Epstein, LPS IX, 1289), Ca (Lee et al., AL 220, 21), Sr (LPS IX, 859), Ba and Nd (McCulloch and Wasserburg, AL 220, 15), Sm (Lugmair et al., LPS IX, 672). The case for extinct ^{26}Al became firmly established (Clayton and Mayeda, GRL 4, 295; Wasserburg et al., GRL 4, 299). Although oxygen and magnesium isotope anomalies are found in a large number of inclusions in several different C2 and C3 meteorites, the anomalous isotopic compositions found in other elements occur in only 2 inclusions taken from Allende. The possibility that a supernova was intimately associated with early formation of the solar system is being explored by a number of investigators.

The isotopic compositions of the noble gases continued to be a subject of intensive study. (Lewis et al., JGR. 82, 779; Frick and Moniot, LSC 8, 229; Srinivasan, GCA 42, 183; Srinivasan and Anders, Science 201, 51).

Several young formation ages ($<$ 4.0 ae) of meteorites were reported. Another nakhlite-achondrite, Governador Valadares, was found to have an age of 1.3 ae as do the other members of this class (Bogard and Husain, GRL 4, 69). Bogard et al. (JGR 81, 5664) found nine ordinary chondrites with degassing ages less than 600 x 10^6 years.

Lead isotope systematics yielded formation ages of Allende white inclusions near 4.5 aeons but indicate late disturbance of the system (Tatsumoto et al., GCA 40, 617; Chen and Tilton, GCA 40, 635). Macdougall and Kothari determined a compaction age of 4.2-4.4 ae for C2 chondrites. The complex chronologies of basaltic achondrites as determined by several dating methods were reported by Unruh et al. (EPSL 37, 1) and by Birck and Allegre (EPSL 39, 37). Fission track dating methods were also applied to achondrites (Carver and Anders, GCA 40, 467, 935; Wilkening and Parker, LSC 8, 313).

The unusual achondrite, Angra dos Reis, was the subject of a consortium study (EPSL 35, 271). A fast cooling rate ($770^oK/10^6y$) was determined by fission track methods (Storzer and Pellas, EPSL 35, 285). This fits in well with the concordant ages (4.55 ae) determined by several other isotopic systems.

Exposure ages were reported include diogenites (Herzog and Cressy, GCA 41, 127), ureilites (Cressy, GCA 40, 1477), iron meteorites (Voshage and Feldman, EPSL 39, 25 and in press), and stony-irons (Begemann et al., GCA 40, 353).

The principal development in terms of mineralogy of the CAI were the discoveries of refractory metal alloys containing Os, W, Re, Ir, Re and Pt and sulfides as minute inclusions within silicate minerals (Palme and Wlotzka, EPSL 31, 45; Fuchs and Blander, GCA 41, 1170; El Goresy et al., MET 12, 215) and the existence of layered rims enclosing CAI's (Wark and Lovering, LSC 8, 95). Lovering and co-workers (LS, VIII, 504) found a suite of U, Th-rich minerals.

Fine-grained CAI's have a complex abundance pattern (Grossman and Ganapathy, GCA 40, 967; Nagasawa et al., GCA 41, 1587), which might be explained by fractional condensation processes (Boynton, GCA 39, 569; LPS IX, 120).

The mineralogy and chemistry of the carbonaceous chondrites were studied by McSween (GCA 41, 411, 477, 1145, 1777, 1843; Richardson and McSween, EPSL 37, 485). Kerridge (GCA 41, 1163) found a correlation between Ni and S abundances in Orgueil phyllosilicates which implies aqueous activity. Richardson's study of veins in C1 chondrites (MET 13, 141) also shows the action of liquid water to have been important in these meteorites. Trace element analyses on C3 chondrites were reported by Anders et al. (GCA 40, 1131) and Takahashi et al. (GCA 42, 97). A new determination of boron reported by Weller et al. (GCA 42, 999; AL 214, 39) is a factor of 6 lower than the Cameron estimate but still 5-10 time the photosphere value.

The structure and composition of the high molecular weight organic material in carbonaceous chondrites was addressed by Bandurski and Nagy, GCA 40, 1397; Hayatsu et al., GCA 41, 1325.

Regarding ordinary and enstatite chondrites, Herndon and Suess (GCA 40, 395 and 41, 233) concluded that both could have condensed from a gas of solar composition at relatively high pressures ($\ngtr$ 1 atm) given certain additional conditions such as hydrogen depletion in the case of ordinary chondrites. Wai and Wasson (EPSL 36, 1) concluded that in order to produce ordinary chondrites some volatiles must be lost prior to final agglomeration. This view is disputed by Anders (EPSL 36, 14) who holds that volatiles were lost during chondrule formation.

Inclusions of various kinds which occur in ordinary chondrites have been used as indicators of accretionary and geological mixing processes occurring on meteorite parent bodies by Fodor and Keil (GCA 40, 177); Fodor et al. (N.M. Geol. Soc. Pub. 6); Wilkening (LSC 7, 3549; MET 13, 1); Clayton and Mayeda (GCA 42, 235); Higuchi et. al. (GCA 41, 843), Davis et al. (GCA 41, 853), Dodd and Jarosewich (MET 11, 1), Leitch and Grossman (MET 12, 125).

Metamorphic effects on the chemical compositions and petrography of chondrites are further studied by Lipschutz and co-workers (GCA 40, 59, 133; 41, 393, 1247, 1398; LS 8, 161). Their results are consistent with open-system metamorphism having been important in establishing the observed abundances of trace elements only in the cases of enstatite chondrites and carbonaceous chondrites.

The size and mass distributions of chondrules were reported for various meteorites by Martin and Mills (EPSL 33, 239; 38, 385); Hughes (EPSL 33, 428 and 38, 391); King and King (MET 13, 47).

The greatly improved understanding of planetary differentiation processes has led to important advances in our understanding of the origin of basaltic achondrites, through the study of mineralogy and petrology, e.g., Dymek et al. (GCA 40, 115), but mostly through the study of geochemical processes which produced the observed trace element compositions of basaltic achondrites (Fukuoka et al., LSC 8, 187; Dreibus et al., LSC 7, 3383, LSC 8, 211; Consolmagno and Drake, GCA 41, 1271; Morgan et al., GCA 42, 27).

Abbreviations: AL - Astrophysical Journal Letters. EPSL - Earth and Planetary Science Letters. GCA - Geochimica et Cosmochimica Acta. GRL - Geophysical Research Letters. JGR - Journal of Geophysical Research. LS - Lunar Science (Abstracts). LPS - Lunar and Planetary Science (Abstracts). LSC - Proceedings of the Lunar Science Conferences. MET - Meteoritics. MM - Mineralogical Magazine. SSR - Space Science Reviews. ZN - Zeitschrift für Naturforschung.

N. RICHTER
President of Commission

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