15. PHYSICAL STUDY OF COMETS
(L'ÉTUDE PHYSIQUE DES COMÈTES)

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NARRATIVE REPORT

A. *Introduction*

The partition of the subject matter of this report follows that of earlier reports. Drafts for individual sections or parts of such were contributed by C. Arpigny, L. Biermann, A. H. Delsemme, O. V. Dobrovolsky, L. Haser, G. Herzberg, B. J. Levin, Rh. Lüst, E. Roemer, V. Vanýsek, and K. Wurm. The overall editing was done by Mrs Rh. Lüst, V. Vanýsek, and the undersigned.

Before mentioning some of the more important developments it is noted that E. Roemer has continued to publish every few months short notes on comets in the Publications of the A.S.P. The annual reports in *Quarterly Journal of the Royal Astronomical Society* have been continued by B. G. Marsden and J. G. Porter.

Several collections of Russian papers have been published which give a survey of the work done in the U.S.S.R. The description of physical characteristics of comets which appeared from 1961–1965 was continued by S. K. Vsehsvjatskij, who also completed a book on *Nature and Origin of Comets and Meteoritic Matter*.

Two new observatories, primarily for comet observations, are under construction in the U.S.S.R.; one at Lesniki near Kiev, the other, with a 70 cm classical paraboloid and a 40 cm refractor, at Hissar.

The Isophotometric Atlas of Comets, edited by W. Hoegner and N. Richter, appeared in 1969. Furthermore the *Atlas of Cometary Forms*, ed. by J. Rahe, B. Donn and K. Wurm, became available in early 1970. An excellent review on cometary tails was written by J. Brandt.

One of the more important developments in our knowledge of the physical parameters which characterize a comet concerns the determination of the gas output. The work of D. Malaise on pressure effects in the rotational band structure of CN in high dispersion spectra of several recent comets led to estimates of the total gas density at a distance from the nucleus of 10^4 km of the order of 10^7 to 10^8 molecules/cm^3, which corresponds to a total outflow of 10^{31} to 10^{32} molecules/s. This result is in substantial agreement with that of three earlier attempts to estimate the total gas output, by L. Biermann and E. Trefftz, by W. Huebner, and by F. Probstein and M. Finson, all of whom had by different methods arrived at similar figures. Though objections may be raised against each of these four methods, the order of magnitude agreement of the results leaves hardly room for any doubt about their essential correctness. This confirms the earlier suggestion that collisions may be important in the inner parts of the heads of comets. Furthermore, it will most probably be possible very soon to measure the hydrogen component of future comets spectroscopically by observing the $L\alpha$ picture by means of spacecraft or stabilized sounding rockets. If hydrogen, as had been proposed by F. Whipple already in 1950, is the most important atomic constituent (by numbers), the proposed measurement will measure also the total gas output.*

Another recent development concerns the lifetime of the parent molecules of CN and C_2. It seems now certain that these do not reach larger distances from the nucleus than approximately 10^4 km.

* **Note added in proof:** In January 1970, Comet Tago-Sato-Kosaka 1969 has been observed with OAO 2 and was found (as expected) to possess a very large hydrogen atmosphere.

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B. *Photometry*

1. *Visual observations*

Visual estimation of cometary brightness is still a method which supplies relatively the largest amount of information on the behavior of the integral brightness of comets. Besides the observations which have been carried out for several decades by the well-known observer M. Beyer (1966, 1969), a considerable number of observations are recorded by groups of amateur observers, for instance, the Comet Section of the Association of Planetary and Lunar Observers in the U.S.A. Only a part of these observations are available through publications scattered in different journals and circulars.

The most comprehensive source of brightness and other physical data of comets was published recently by Konopleva *et al.* (1967, 1968).

A critical analysis of visual data of some recent comets was made by Meisel (1969b), who discussed different reduction methods. The Bobrovnikoff telescope-aperture correction, applied to the standard reduction formula, seems to be the most efficient simple reduction method. Meisel's (1969a) results for the periodic Comet Tempel 2 indicates no fast decrease of "absolute" magnitude and he concluded that all estimates of a secular decrease of cometary brightness may be suspect. The average "absolute" visual magnitude of P/Tempel 2 was 9.4^m in the years 1873–1894, in 1925 increased to $11{\cdot}3^m$, and in 1967 is again near $9{\cdot}4^m$.

Dobrovolskij and Osherov investigated the dependence of the visible brightness of comets on the geocentric distance and showed statistically that the inverse square dependence may be more nearly correct than an inverse linear dependence suggested recently by Öpik.

2. *Photographic photometry*

Integral photographic magnitudes were published by Garasdo-Lesnyh and Konopleva (1969) for Comet Kilston 1966 V, whose brightness was almost constant in the range $9{\cdot}6^m$ to $9{\cdot}9^m$, and the mean error of one measurement was $\pm 0{\cdot}2$ to $\pm 0{\cdot}3^m$.

The photographic methods are more widely used for the study of intensity distribution in the cometary head and tail.

The spectral gradient of the cometary continuum, according to a recent photographic spectrophotometric study by Pflug (1967) of Comet Arend-Roland 1957 III is close to that of K2V stars and depends slightly on phase angle.

Microphotometry of tails of Comet Ikeya-Seki 1965 VIII with accuracy of about 5% was carried out by Vsehsvjatskij *et al.* (1968) and utilized to study the tail kinematics. Nazarchuk (1969) published a similar analysis of the distribution of intensity in the tail of Comet Arend-Roland. The equidensity method for study of coma and tail structure based on the Sabbatier effect was successfully developed by Hoegner and Richter. Their *Isophotometric Atlas of Comets*, which was recommended by Commission 15 at the Prague Assembly in 1967, became available in late 1969.

3. *Photoelectric photometry*

Photometry, both in narrow bands as well as in the standard UBV system, was used more widely in recent years. In a routine photoelectric program using the UBV system, Mrkos *et al.* (1968) obtained photometric data for Comets 1966 V, 1967 XI, 1968 I, 1968 VI. The unusual intensity distribution in cometary spectra when emission bands are present has the result that the observed color of comets cannot be perfectly transformed to any conventional color system. The U filter covers only the CN $\Delta v = 0$ band, while the V filter includes the $\Delta v = 0$ and $\Delta v = +1$ band sequences of C_2. Generally, the $U-B$ color is more sensitive to the behavior of cometary spectra than the $B-V$.

Bappu and Sivaraman (1967) used five interference filters with a half-width of about 50Å for photoelectric measurements of emission bands as well as continuum. Two of these filters were for CN($\Delta v = 0$) and C_2($\Delta v = +1$) bands, and the continua regions were centered at $\lambda = 4310$Å, 4860Å (Hβ) and 5890Å. The measured fluxes were utilized to determine absolute abundances of CN and C_2 which were found to be $10^{29.2}$ and $10^{30.2}$ molecules in the observed region of the coma. Energy

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distribution in the cometary continuum was similar to that of G8V stars, which is in agreement with a reddening of the cometary continuum observed in almost every previous photometrically or spectrophotometrically studied comet.

Vanýsek (1969a) found an unusually low relative molecular abundance of C_2 with respect to CN in "dust rich" Comet Ikeya-Seki 1967n from monochromatic measurements in CN($\Delta v = 0$) and C_2($\Delta v = +1$) band sequences as well as in the continuum region near 4860Å. The paucity of accurate photoelectric observations of comets is due partly to the fact that it is very difficult to reconcile the needs of cometary photometry with those of stellar photometry, especially in the three-color UBV system.

Since the H_β and uvby system is more widely used in stellar photometry, the possibility of successful application of a "stellar" color system to cometary photometry increases. The b and H_β filters in the H_β + uvby system can be used without any change for measuring C_2($\Delta v = +1$) emission bands and continuum flux near the H_β wavelength. The region close to 4860 Å is not contaminated by molecular emissions. Therefore the H_β photometry and b color regions seem to be the best choice for the recommended basic "two color" system for future routine cometary photometry, i.e. the minimal number of spectral regions required for the photometric studies of comets. Such a simple two-color system could be very effective for observations of faint comets and especially of brightness outbursts when the contribution of dust and gas to a sudden increase of coma brightness cannot be determined from observation in only one spectral range.

C. *Spectroscopy*

No really bright comet, suitable for high-dispersion spectrographic observations, appeared during the period under review, so that the published work in this field as well as the present report are to a great extent concerned with the recent sun-grazing comet, Ikeya-Seki 1965 VIII.

At the Lick Observatory, spectra of this comet were taken by Preston (1967) before perihelion passage at a heliocentric distance $r \sim 0{\cdot}4$ AU and after perihelion passage at the closer distance $r \sim 0{\cdot}14$. The latter are, of course, daytime observations. The spectra for the larger distances contain the usual cometary emissions CN, C_2, CH, C_3. The spectra taken at $r \sim 0{\cdot}14$ are governed by many emission lines, the strongest ones belonging to Na I, K I, Fe I, Ni I, Cu I. CN and Ca II are also present. Because of the brightness of the night sky the cometary emissions are detectable on the plates only at and close to the cometary nucleus. The lengths of the lines of highest intensity (Na D-lines) do not extend beyond 25″ (= 17500 km) from the center of the nucleus. The numerous Fe lines are less than half as long. A curve-of-growth analysis of the Fe I spectrum leads to a formal excitation temperature of 4500 K, the line intensities of Na I and K I to only 2600 K. Attempts to determine relative abundances of the observed elements seem to indicate an anomalously low K/Na and a very high Cu/Fe ratio. However, these results are unfortunately not very significant because the fluorescence excitation of the observed emissions has not been properly taken into account. Both the relative and the absolute number densities will have to be revised.

A similar analysis has been carried out by Slaughter (1969), who gives a very extensive list of line intensities for several points in the head and tail of Comet Ikeya-Seki just prior to and after perihelion from 1·1 mmA^{-1} spectra taken with the Kitt Peak solar telescope. Spinrad and Miner (1968) studied the structure of the Na D-lines of Comet Ikeya-Seki on high dispersion spectrograms (5 mmA^{-1}) obtained at the same period and with the same instrument. Since the heliocentric radial velocity was -187 km/sec, the comet's resonance wavelengths were shifted into the full solar continuum near λ5890. The spectrograms were secured with the slit through the nucleus at several position angles. The Na D-line emission spreads in the tail direction to some 100000 km, and normal to the comet-sun line to about 40000 km from the nucleus. The emission was most intense at and on the sunward side of the nucleus, but decreased rapidly in this direction. The Na coma must have had a shape similar to the one obtained theoretically from a fountain type model for a particle suffering a high repulsive force. However, this simple Na fountain model cannot be correct, since the lifetime of the neutral Na atoms until ionization was certainly much too short to reach the

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observed distances from the nucleus. The apparent fountain model shape must have been brought about by a precursor, probably small grains, which spread from the nucleus and released Na atoms not earlier than after a few hours. This idea of the authors is very probably correct.

Measurements of the polarization of the Na D2-line in Comet Ikeya-Seki made by Hyder (1966) were originally interpreted by him as due to a magnetic field which is dragged along with the comet. A more detailed discussion by Chamberlain (1967) revealed, however, that cometary observations of this type should not be affected by magnetic fields of such a small strength as would be expected here.

On the basis of high dispersion CN spectra of several rather bright recent comets Malaise (1970) tried to arrive at a refinement of the physics of cometary head atmospheres for heliocentric distances between $r = 1$ and $r = 0{\cdot}5$ A.U. Synthetic model structures of the (0, 0) band of CN constructed by taking into account all conceivable physical factors influencing intensities and profiles of the lines are compared with structures observed for one and the same comet close to the nucleus and at larger distances from it. According to the author there exist, in addition to the heliocentric distance, five other variable physical parameters which determine the finer shape of the band branches; of these the total gas density and the gas temperature are the most important ones. The numerical values of the parameters of the eight cases reported in the paper, which are internally consistent, were determined by attempting the best fit between the synthetic and the observed spectra. The most important result of the analysis is that the collision zones of the neutral coma atmospheres, where the rotation of the molecules is influenced by particle collisions and in which we might therefore expect bimolecular reactions, are much further extended than has hitherto been assumed by most authors. Concerning the total densities the author estimates for a distance $D_0 = 10000$ km from the nucleus minimum values between 10^7 and 10^8 cm^{-3}. Despite the careful work of the author and the excellent spectra used doubts may, nevertheless, remain whether the results are actually correct. Cometary heads are no neutral atmospheres as assumed, and it may well be and it is even probable that the more or less continuous stream of visible and invisible ions from the head through the whole coma is more effective in producing collisions than that of the neutrals among themselves. (See also section on type I tails.) It is accepted that such collisions are in fact necessary to explain the spectra. However, if one admits minimum densities of 10^7 to 10^8 cm^{-3} at $D_0 = 10000$ km, it is difficult to understand how narrow ion streamers with an observed origin close to the nucleus remain undisturbed throughout the whole coma despite the moderate flow velocity within them.

D. *Structure and origin of the nucleus*

Seemingly fundamental criticisms by Lyttleton of the reality of the Oort cloud of comets as a maximum in the space density of orbital aphelia have been answered by Le Poole and Katgert (1968), who point out that this is an incorrect interpretation of Oort's ideas. Sekanina, in two papers in *Bulletin of the Astronomical Institute of Czechoslovakia* investigates the perturbations of nearby stars on the comet cloud, extending earlier work by Makover, Steins and Sture, and others. He concludes from detailed study of the sphere of action of the solar system that, due to perturbations by α Cen, the Oort cloud would not remain under the influence of the solar system for extended periods of time. Encounters of interstellar comets with fast-moving stars are considered in the second paper. Vsehsvjatskij (1968) also sees difficulties in persistence of the comet cloud because of many close stellar approaches since the origin of the solar system.

Everhart (1967) has attempted to derive the intrinsic distributions of several orbital elements of long-period comets and the distribution of their absolute brightnesses from a more detailed study than has been attempted previously of effects of observational selection on discoveries.

Hamid *et al.* (1968) have concluded from an investigation of secular perturbations of the orbits of a number of short-period comets that a belt of comets exceeding one earth mass within a distance of 50 A.U. from the sun is excluded.

Recent findings regarding nongravitational effects in the motion of comets appear to modify substantially the entire picture of hyperbolic original and future orbits (Sekanina, 1967a).

With definitely observable nongravitational effects on the motions of many periodic comets now convincingly established (Marsden, 1968; Sekanina, 1968b), investigation has turned to analysis of the character of such effects. Marsden (1969) finds that a continually acting force, decreasing in intensity with time, explains the greater part of the deviations from gravitational motion. A radial component, almost invariably outward from the sun, generally dominates. The transverse component is about an order of magnitude weaker, while there appears to be no significant force component perpendicular to the orbit plane. There is some evidence of additional effects, presumably random and impulsive in nature. Sekanina has developed the model of nongravitational effects associated with a rotating nucleus, an idea first suggested by Whipple in 1950, in a series of seven papers in *Bulletin of the Astronomical Institute of Czechoslovakia* under the title "Nongravitational Effects in Comet Motions and a Model of an Arbitrarily Rotating Comet Nucleus". Sekanina suggests that splitting of the nucleus can be caused by an explosive ejection of material from a fragile nucleus, the fracturing being simultaneous with an impulsive effect on the orbital motion. In a few cases nongravitational forces have been large enough to produce clearly observable effects during a single perihelion passage. An outstanding example is Comet Burnham 1960 II. There also appear to be anomalous nongravitational effects associated with close approaches of individual comets to Jupiter. Marsden and P. Stumpff are working on this problem.

The magnitude of nongravitational effects on individual comets seems to be correlated with their apparent diffuseness. The fact that the motion of comets of asteroidal appearance can be represented gravitationally has led Marsden (1969) to suggest that such objects represent a transition phase between a comet and an asteroid of the Apollo type. This suggestion is particularly interesting in view of the fact that Monte Carlo calculations by Wetherill, aimed at identification of the source(s) of meteorites, seem to be leading to similar ideas regarding a relationship between Jupiter-family comets and Apollo asteroids (Wetherill, 1968). Öpik (1968) also has further developed his ideas on the cometary origin of meteorites, suggesting that fragments resulting from planetary collisions have been embedded in the ices of cometary nuclei.

Studying the origin of the Kreutz group of sungrazers, Marsden (1967) has presented considerable evidence that the sungrazers fall into two very compact groups, defined by strikingly similar orbital elements. He suggests that each group is composed of fragments of a comet disrupted only one or two revolutions ago, probably by tidal effects near perihelion. These parent comets may derive from disruption of a very large comet in the more remote past. Sekanina (1967b) considers that collisions of a massive proto-comet with a "cosmic projectile" at some distance from perihelion is a preferable hypothesis, with subsequent evolution of the dynamical characteristics of the group of sungrazers through less violent means.

Harwit (1968) has pointed out that splitting of all the comets studied by Stefanik occurred close to the ecliptic plane. Sekanina has studied splitting and impulsive perturbations of orbital motion both for individual events and as part of his more general studies of nongravitational effects. Objects studied include the sungrazer Ikeya-Seki 1965 VIII, P/Biela, and Comet Wirtanen 1957 VI (Sekanina, 1968a).

Roemer (1968) has found that the populations according to nuclear radius of periodic and near-parabolic comets are similar, the cumulative number of objects with radius larger than R being represented in the form $N = N \cdot R^{-s}$, with $s = 1{\cdot}5$ in each case.

Markovich and Tulenkova (1968), solving the heat conduction equation numerically, conclude that in the 30 days including perihelion passage, the sungrazing comet Ikeya-Seki must have lost mass amounting to 10^{14} g. Sekanina's recent work also includes theoretical calculations of heat and mass transfer in model comet nuclei as well as an attempt to reconcile directly observed mass loss rates of C_2 with the total mass loss rates derived dynamically for representative short-period comets.

E. *The coma*

Study of the heads of comets in monochromatic light has led to new data determining the mean paths τv (lifetimes $\tau \times$ ejection velocities v) of the observed radicals, as well as their hypothetical precursors (Miller, 1967; Vanýsek and Zacek, 1967; Vanýsek, 1968a and 1969a). C_2 and CN were often measured, C_3 and CH more rarely, the other radicals practically never; this is a pity for it neglects major constituents whose oscillator strength is weak, like OH. The observations by and large confirm the former value of the lifetimes of the radicals decaying in the solar field. The dependence of the total brightness of a given radical on heliocentric distance is not very well known. A good determination for Comet Rudniczki 1967 II (Mayer and O'Dell, 1968) shows that the desorption heat as defined by Levin's law is lower for C_3 than for C_2 or CN. However, the behavior often seems erratic because of outbursts.

More attention has been given to the lifetimes of the assumed precursors. Some knowledge has been gained by trying to fit the brightness profiles with Haser's model and selecting the best ratio for the radical/precursor lifetimes. For Comet Everhart 1964 IX, the best fit for this ratio is 10, but 5 is almost as good (Vanýsek and Zacek, 1967). The ratio seems to be the same for C_2, CN, and C_3. Malaise (1968) uses a simplified procedure on Comets Burnham 1960 II and Ikeya 1963 I, because his observations exclude the outer coma; the dependence of the precursors' mean paths on the heliocentric distance suggests that photodissociation can produce C_2 but not CN nor C_3; his study of the population of the rotational levels emphasizes collisions in the coma.

Upper limits of the precursors' lifetimes, often near 10^4 sec whatever the neutral radical concerned, are reached by other methods (Wurm and Vanýsek, 1969; Vanýsek, 1969b). By contrast, the upper limit for the CO^+ precursors' lifetime, the only ion seriously discussed, is much shorter. Wurm and Mammano (1967), Wurm (1968), Rahe (1968), Rahe and Wurm (1969), Rahe and Donn (1969) have accumulated more evidence of this fact, which has not yet been satisfactorily explained by any process. Jackson and Donn (1968), in a comprehensive analysis, conclude that photodissociation is adequate to explain observed steady state densities of radicals observed near the nucleus of a comet. However, none of the identifications of any hypothetical precursor with actual molecules has yet been successful in explaining lifetimes. The discrepancy is still one full order of magnitude. New unstable molecules could of course still be identified with precursors.

Another way of avoiding this difficulty is to build a model of the coma where the precursors are large ice grains stripped from the nucleus and evaporating in the solar field (Delsemme and Miller, 1969). Contrary to an earlier approach by Huebner and Weigert, a large optical depth which drastically limits the particle size is not postulated here. The shape of photometric profiles of both inner coma and continuum can be explained by radicals evaporating from a clathrate lattice in the grain. The presence of solid grains in the coma is now receiving much attention. Finson and Probstein (1967) as well as Shulman (1969) applied a gasdynamic approach to a flow in the nuclear region and showed that dust particles will be accelerated to velocities up to several hundreds of meters per second.

The continuum in the head and its polarization have been compared with theoretical size distributions of particles (Donn *et al.*, 1967). The polarization observed is too low for iron spheres but can be explained by dielectric grains. The bulk of cometary grains cannot have sizes larger than a few microns without requiring excessive mass, but a fraction of larger particles is not ruled out. An increase in the ratio of the intensities of the continuum/molecular emissions has been observed near inferior conjunction; Vanýsek (1968b) suggests that it comes from a forward scattering effect of the dust halo, which originates from particles whose size is at least as large as λ. Krishna Swamy and Donn (1968) study grain temperatures; the results are not corrected for the latent heat of evaporation at small heliocentric distances. Kaimakov and Sharkov (1967a) note that the escape velocity of dust grains is governed by temperature only, and depends little on the grain size. Dolginov (1967) and Egybekov (1969) study the formation of grains in the coma. To explain the decrease of brightness after a perihelion passage, Huebner (1967) must use a reduction of the sublimation rate.

At small heliocentric distances, other grains less volatile than ices are likely. Huebner (1970) studies the vaporization of sodium grains at short heliocentric distances. The Kovars (1968) show that the anomalous ratio of the Na I D doublet cannot come from a fluorescent mechanism only. They study (1969) the problem of the lifetime of Na I. Cherednichenko (1968) shows that the [O I] red line might partly come from dissociative recharge of ions O_2^+ with Na; the green line from dissociative recombination of ions NO^+ with electrons. The asymmetry of the coma is too often neglected. Miller (1967) measures the oblate form of the C_2 coma of 1960 II; he shows (1969) its perfect symmetry in Comet Honda 1968 VI, as opposed to the asymmetry of dust ejection. This obvious non-interaction of gas and dust at larger distances from the nucleus is satisfactorily explained by Finson and Probstein's theory (1968); the drag forces occur only in the inner head.

The hydrogen atmosphere of comets to be expected on the basis of current concepts of their chemical constitution and gas production has been studied by Biermann (1968) in order to provide estimates for the extent of the hydrogen coma, which might be observed in the light of $L\alpha$ by means of stabilized sounding rockets or space probes (cf. sections A and J).

F. *Type I tails*

No new comets with conspicuous plasma tails were observed over the last three years. In the tail spectrum of Comet Ikeya-Seki 1965 VIII the atoms dominated as compared to ions including molecular ions. The interpretation of the ion features near perihelion was discussed by Lüst and Schmidt (1968).

Plates of Comet Morehouse were rediscussed by several authors with the aim to determine certain parameters with higher precision than before or to investigate the compatibility with recent theoretical work. Lüst (1967) has measured the motion of envelopes in close distance of the head and discussed the possibility that these features are identical with the contact surfaces between cometary and solar wind plasma postulated by theory. Also, velocities of tail particles were deduced. Stumpff (1967) compared these findings with values in greater distance of the head, made by Wolf, and deduced a velocity field of the streaming tail material. Also Schlosser (1968) derived velocities and accelerations of tail structures. He found a decreasing acceleration with increasing distance from the nucleus, and no dependence of the velocities on the distance from the tail axis in contrast to other authors. Several other papers by Schlosser (1966, 1967), and Schlosser and Hardorp (1968) deal with the evolution of the wavy tail rays observed in this comet. From the wavy structure, a directional fluctuation of the solar wind was postulated. The bulk velocity of the solar wind in high heliographic latitudes ($+46°$) deduced from the aberration angles of the tail axes agrees with satellite measurements near the ecliptic plane.

Brandt's work on the statistics of the direction of cometary plasma tails as indicators of the direction of the solar wind flow was continued. In his first paper (Brandt, 1967), he compared the values for the bulk velocity of the solar wind derived from a great number of observations of tail aberration angles from different comets with values from the Mariner II mission and from geomagnetic storms. All values are in good agreement. Further, evidence was found for a mean tangential component of the solar wind velocity near the earth of ~ 9km/s directed in the sense of solar rotation. – A curious dependence of the solar wind velocity on heliographic latitude was found by Pflug (1966). From similar statistical material he derived that the solar wind velocity has a minimum between heliographic latitudes 20° to 30°, i.e. above the solar activity belts. According to Brandt, these findings might, however, be influenced by a biased sample of comet observations. Dispersions in the tail orientation were interpreted as being caused by discontinuities in the interplanetary medium by Brandt and Heise (1969). The authors confirmed the existence of a mean azimuthal plasma velocity of 9 km/s in the sense of co-rotation; this velocity component was furthermore found to be largest at periods of high solar activity.

Theoretical work on the interaction of the tail plasma with the solar wind was continued by Ioffe (Tadzhik State University), by Biermann, Brosowski, Meyer and Schmidt (Munich), and by Wallis (Manchester). The approach in most cases was the use of magneto hydrodynamics without explicit introduction of the magnetic field. Ioffe (1967) represented the comet by a line source of plasma, and the observed accelerations were related to the field of flow assuming approximate equality (within a factor of 2) of the magnetic tension and the pressure at the stagnation point, Wallis (1967, 1968) gave particular attention to a pure CO comet, whereas the work done in Munich was based on the concept of distributed sources using the picture developed earlier by Biermann and Trefftz (Biermann *et al.*, 1967; Brosowski and Schmidt, 1967).

Nazarchuk and Shulman (1968) developed a diffusion model of a plasma tail which was checked observationally and used for the estimate of tail plasma characteristics on the basis of brightness distribution in the tails of Comets Arend-Roland 1957 III and Mrkos 1957 V.

The determinations of the total gas production of a comet discussed in the introduction are of course basic to future discussions of the comet – solar wind interaction.

A new line of approach has become possible from the measurements of the rate constant of the dissociative recombination of CO^+ (see the section on laboratory work). From this it became possible to give a lower limit for the distance from the nucleus, at which the CO^+ is being formed, and an upper limit for the electron collision rate which turns out to be somewhat smaller than that of molecular collisions (Biermann, 1970).

From a list of 89 comets observed photographically since 1880 with information about type and length of tail, brightness, spectrum etc., Vsehsvjatskij (1969) tried to correlate the maximum tail length to perihelion distance, from which he drew conclusions about the composition of the tails. New classification criteria were proposed.

A summary of our knowledge concerning the structure of type I tails was presented by Wurm (1968).

G. *Type II and III tails*

Since Bredikhin's time type II tails of comets were usually regarded as syndynames with $1-\mu \sim 1$ to 2, it was difficult to combine this notion with the assumption that these tails are composed of dust. Therefore a hypothesis that they are composed of neutral gas had been put forward by Levin. The discovery of the presence of atomic oxygen in comet heads increased by several orders of magnitude the estimates of gas densities in the heads and of the rate of evaporation of the nucleus (see Introduction and section on cometary heads).

Dobrovolskij *et al.* (1966) reported their measurements of the position of the tail axis of Comet Arend-Roland 1957 III, from which they concluded that the tail was not a syndyname or a synchrone, but was produced by a continuous emission of particles of various dimensions. Clearcut evidence was not presented in this note. Later Finson and Probstein (1968) came to the same conclusion from the analysis of isophotes of the tail of this comet. They definitely showed that this dust tail was produced by a continuous but peaked emission of dust particles with various values of $1-\mu$. Peaks of dust emission produce type III tails which in case of a small rate of continuous emission cannot be superimposed on or combined with type II tails.

Thus it became clear that for previous comets reported to have type II tails, there is no convincing evidence that these were syndynames with $1-\mu \sim 1$ to 2. The nature of so-called "synchronic bands" sometimes observed in type II tails remains to be explained.

Dolginov (1968) showed that interplanetary dust particles can acquire rapid rotation and orientation under the influence of the solar wind. Such orientation can also take place in dust tails of comets and is manifested in their light scattering properties.

H. *Laboratory work*

Physicochemical studies of the evolution of gases and dust from comet nuclei have been handicapped by deficient knowledge of the behavior of possible cometary materials at low temperatures (50–200 K) and pressures. Efforts to fill this gap experimentally are being made by Kaimakov and Sharkov (1967b), who have studied water ice, and by Delsemme and Miller who are measuring vapor pressures of CH_4, NH_3 and their hydrates (see section on coma).

Furthermore a good deal of work has been done in various laboratories on the spectra of diatomic molecules which are of interest in connection with cometary spectra. These include CH (Herzberg and Johns, 1969), CH^+ (Carré, 1969), NH (Murai and Shimauchi, 1966; Horani *et al.*, 1967), NH^+ (Colin and Douglas, 1968). OH (Czarny and Felenbok, 1968), OH^+ (Merer *et al.*, 1969), SiH (Herzberg *et al.*, 1969), SiH^+ (Douglas and Lutz, 1970), C_2 (Phillips and Davis, 1968; Lagerqvist *et al.*, 1970), AlO (Mahieu and Bécart, 1968; McDonald and Innes, 1970). The transition probabilities for the Swan and Mulliken C_2 bands were newly determined by Smith (1969). In addition, a good amount of photoionization work has been reported, for example, on CO, which is obviously of considerable interest in connection with the question of the formation of the ionized molecules in comets. The rate constant of dissociative recombination of CO^+ has been measured by Mentzoni and Donohoe (1969) (for preliminary conclusions see section on type I tails). The ionization potential of CH has been determined from a Rydberg series to be 10·64 eV. Finally, experiments have been carried out on the fluorescence of a number of polyatomic molecules when excited in the far ultraviolet. For example (see Judge *et al.*, 1970), CH_4 gives in fluorescence the spectrum of CH, while C_2H_2 gives both CH and C_2 spectra by absorption of light quanta in the region below 900 Å.

Furthermore laboratory physics of comets is being carried out at the Ioffe Physical and Technical Institute at Leningrad under the guidance of Konstantinov. The sublimation rates, heats, and temperatures have been measured for pure H_2O when mixed with dust. The experiments show that an icy nucleus may remain solid at heliocentric distances much less than 1 A.U. At $T > -50$°C a hotbed effect was observed. The formation of a dust matrix and the dynamics of the dust particle outflow have been investigated.

Simulation experiments to study the flow in the coma of dust comets have been carried out by Brunner and Michel (1968). Atomic resonance absorption spectroscopy in a density range where dipole interactions determine the line widths was experimentally shown to be a useful tool for gas dynamic studies (Brunner, 1969). The experiments by Danielsson (1966) for a simulation of the solar wind interaction with comets have been continued.

J. *Space experiments*

During the period covered by this report several theoretical studies were prepared concerning rendez-vous-missions to a comet. (NASA-reports by Brereton *et al.*, 1967; Friedlander, 1967; Eades, 1968). The feasibility of such a mission has been proved, but high costs and the lack of a suitable comet have so far prevented the execution of such projects. A review about plans for a cometary mission is given by Lüst (1969).

Sounding rocket experiments prepared for the observation of the UV spectrum of comets were launched during the appearance of Comet Ikeya-Seki 1965 VIII, but no results have yet been reported. In any case this object would not have represented a typical comet because of its sungrazing orbit.

In several institutions sounding rocket experiments are being prepared. Spectrographic equipment combined with stabilizing and pointing units are designed mainly to study the spectrum between 1100 Å and 3500 Å with resolutions of about 30 Å. In at least one such experiment, attention is given to the hydrogen Lα emission (cf. sections A, note added in proof, and E).

A barium plasma cloud experiment was performed by the Institute for Extraterrestrial Physics, Garching, in the magnetosphere at a distance of 12·5 earth's radii to study the interaction with the dilute magnetospheric plasma (Haerendel and Lüst, 1970).

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