15. COMMISSION POUR L'ETUDE PHYSIQUE DES COMETES

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INTRODUCTION

The treatment of the Draft Report of Commission 15 follows closely the recommendations given in Document NGP/13 of the General Secretary. The report is composed of three parts: (I) A Narrative Report underlining where (in the opinion of the undersigned) the most important progress has been made; (II) An Administrative Report with reports and plans for co-operation between members; (III) A Comprehensive Bibliography with short abstracts.

The undersigned has to thank several colleagues who have given him important assistance in supplying him with parts of the bibliography together with short abstracts: M. Beyer (photometry), F. J. Whipple (structure of nucleus), P. Swings and D. Malaise (spectroscopy), and G. Herzberg and B. Rosen (laboratory work). Very helpful to the writer were also two summary reports by P. Swings (recent progress in cometary spectroscopy; possible contributions of space experiments in the field of cometary physics) which were made available to him before publication. Summary reports about space research programmes were also received from B. Donn.

For the contents and formulation of the Narrative Report the writer has alone to be considered as responsible.

PART I. SCIENTIFIC REPORT

Photometry

In his publication *Physische Beobachtungen von Kometen XII*, M. Beyer (**10a**) reports on the determination of the visual magnitudes of 11 different comets in the years 1958 through early 1961. Among the 11 objects are the four comets of short period: Schwassmann-Wachmann I, Giacobini-Zinner, Schaumasse and Encke. Beyer was able to observe a strong outburst of the first-mentioned comet over all phases; it started about 1959 October 1, when the brightness (normally about 18^{m}) had already risen to $11\overset{m}{.}5$, the comet appearing, however, still star-like. On October 2 it was $11\overset{m}{.}2$ with slightly diffuse appearance. The author distinguishes between a star-like nucleus, a coma of 11″ diameter and a halo of 60″ diameter. The expanding coma could be followed until November 4 and reached at this time a diameter of $1 \cdot 1 \times 10^{6}$ km, with an average velocity of expansion of 187 m/sec. Maximum brightness of the burst was observed with $10\overset{m}{.}7$ on October 5. M. Beyer received, from K. Lübeck, objective-prism spectrograms made on October 7 and 9; these showed (as was also always earlier found with this comet) a pure continuous spectrum without band lines. Compared with the solar continuum, the comet continuum appears strongly reddened.

Beyer's list also contains Comet Burnham 1958 *a* for which W. M. Sinton (**16**) has published photo-electric magnitudes for different diaphragm diameters obtained with different filters. Beyer compares Sinton's results for the visual region with his own values (making an adequate extrapolation of the photo-electric magnitudes to larger coma diameters) and finds satisfactory agreement.

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M. Beyer's next paper (publication XIII) gives observations of Comets Wilson-Hubbard 1961 *d*, Humason 1961 *e*, Tuttle-Giacobini-Kresak 1962 *b*, Seki-Lines 1962 *c*, and Honda 1962 *d*. The short-period Comet Tuttle-Giacobini-Kresak was observed by the author also during its apparition eleven years earlier. In respect of brightness, brightness variation and shape, the comet showed in both apparitions an equal behaviour. Observations of comets Ikeya 1963 *a*, Alcock 1963 *b*, and Kearns-Kwee 1963 *d* are being prepared for publication; for Comet Alcock the strong burst, which occurred on May 27/28, was observed.

A new burst of Comet Schwassmann-Wachmann I in 1961 is reported by E. Roemer (3); again an expanding nebulosity became visible. The expansion velocity was determined to 0·1 km/sec.

Many determinations of the magnitudes of comets during the last three years have been made by S. K. Vsekhsvyatsky at Kiev (**18**). This author gives also a supplement of his well-known catalogue of absolute magnitudes (**18a**).

A rather important critical paper concerning the determination of absolute magnitudes of comets (natural and artificial) has recently been published by E. J. Öpik (**14**). The author comes to the conclusion that, because of the peculiarities in the distribution of light in the coma, the estimated brightness of comets varies inversely as the first power of the distance from the observer instead of the traditionally-used second power. The effect is, in particular, of high importance in relation to the estimates of brightness made for the planned artificial comets; according to Öpik, the real brightness to be expected is such that the construction of artificial comets is prohibitive.

Structure of the nucleus

Discussions about the nature of cometary nuclei were much stimulated when F. L. Whipple (**31**) published his ideas about the 'icy-conglomerate' nature of cometary material. The principles of this conception are known well enough not to need repetition here. It is also well known that R. A. Lyttleton (**24**) defends a diffuse nucleus concept. In their most recent formulation, Lyttleton's arguments in favour of his new version of the 'sand-bank' model and in opposition to Whipple's picture can be found in N. B. Richter's (**1**) second (English) edition of *The Nature of Comets*. It may be mentioned in passing that Richter himself advocates a more-or-less small, compact, structure of the nuclei. In Lyttleton's accretion theory, the comets arise as aggregations formed by gravitational condensation at large distances from the Sun. The dust particles spread right through the whole observed coma and are all in free motion round the Sun. In Vol. IV of *The Solar System*, F. J. Whipple (7) has discussed and summarized the difficulties of the 'sand-bank' model and the evidence for a discrete cometary nucleus of a partly icy nature. Here are the main arguments. Sun-grazing comets must consist of blocks of at least metres in dimension, in order to account for their continued existence after perihelion passage. The gas-to-dust ratio in large comets is too large for absorption of the necessary gases in Lyttleton's model. The large mass-estimate demands that the nucleus consists essentially of, at most, a few large, discrete, particles. The observed nearly Newtonian motion of comets requires that the dimensions of the particles of the nucleus be of the order of centimetres, in order that light-pressure effects will not appreciable change the effective solar gravity. The 'sand-bank' model gives no explanation whatsoever for the great bursts in cometary brightness which have been observed.

Highly interesting in connection with Whipple's arguments are the observations made at the Asiago Observatory of the gas and dust burst which started in Comet Alcock 1963 *b* on the night of May 27/28. The photographic and spectrographic observations (122-cm reflector and 40/55-in. Schmidt-telescope) of the comet cover largely the whole burst (publication by Chincarini, Margoni and Wurm is being prepared for the periodical *Icarus*). The brightness of the comet increased by 3^m from May 27/28 to 28/29, falling back to somewhat above the

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original value after four or five days. This event was accompanied by the appearance of a spherical gas shell (mainly CN and C_2) expanding with a velocity of 1 to 1·5 km/sec. After interruption of the observations for a few days, we observed on June 6/7 a 'jet' issuing out of the nucleus region in a direction opposite to the Sun, showing a strong continuum and spreading gas and dust to either side. The narrow jet was steadily growing in length, but decreasing slowly in brightness (observations until June 20). The tip of the jet was moving with a velocity of 50 m/sec, the orbit being slightly curved (in the sense of trailing behind the radius vector). The main conclusions which we draw from the observations of the outburst are the following. The solid mass of a comet occupies normally a small space in the centre of the coma. Bursts of solid material from the nucleus can have discrete directions. Small dust particles of a burst lose rather quickly the volatile gases stored in them; this follows from the short duration of the main gas outburst, and is in accord with the gas-free character of the dust tails of comets. The expansion velocities of the gases found here are of the same magnitude as derived from the expanding halos of Comet Halley 1910 by Bobrovnikoff (**19**). The velocity of the material in the jet can be regarded as originating from an acceleration in an 'explosive' gas expansion. The lack of symmetry in the spectra of Comet Alcock after the outburst is just opposite to that which can be recognized in the spectra of Comet Mrkos 1957 *d* reproduced by Greenstein and Arpigny (**45**), and much more pronounced, appearing also strongly in the emission bands. Evidently, the emission of solid material from the nucleus may be either towards or away from the Sun, and possibly in any direction. E. Roemer (**3**) mentions this already in her article 'Comets: Discovery, Orbits, Astrometric Observations', when comparing a photograph of Comet Encke 1960 *i* with one of Comet Baade 1955 VI.

As is well known, there exist many comets with a tendency to irregular bursts of light, Comet Schwassmann-Wachmann 1 (1925 II) being the most spectacular specimen of this group.

In his book (**1**) N. B. Richter gives an informative survey of its best known members. E. Roemer (**3, 27**) also deals with this phenomenon on the basis of her own experience. One can conjecture that the underlying physico-chemical process is in all cases essentially the same, and may even partially explain the observed disruptions of a nucleus into two or more pieces which afterwards form new individual comets. The splitting of Comet Wirtanen 1957 VI into two separate comets is described by E. Roemer (**3**).

R. E. Squires and D. B. Beard (**29**) publish a paper concerning the influence of mass loss on the trajectories of long-period or parabolic comets. They assume that, as a comet approaches perihelion, there is evaporation of the surface material in the solar direction. The effect of this radial push away from the Sun is found to change the cometary orbit in such a way as to cause the observed portion of the orbit to differ significantly from that part of the orbit where the comet is invisible. They conclude that the true periods of long-period comets are much smaller than is generally believed. According to the reports in the previous paragraph, one must ask whether the assumption by the authors of an uni-directional evaporation to the Sun has any justification.

Z. Sekanina (**28**) considers the physical consequences of collisions between comet nuclei and interplanetary dust particles. As one would expect, the pulverization process itself is not sufficient to explain the amount of dust in cometary atmospheres. The author regards it as possible that these collisions may, however, be responsible for a number of cometary outbursts (which seems not very probable to the writer).

B. Y. Levin (**23**) proposes the hypothesis that the components of icy cometary nuclei are not stony substances but separate atoms and molecules of a non-volatile type embedded in the amorphous, non-coherent condensate of different volatile substances.

E. J. Öpik (**26**) concludes that icy cometary nuclei do not finally sublime to complete extinction but can become inactive to provide a source for Earth-orbit-crossing 'asteroids' of

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the Apollo group. He bases his argument on a theory concerning the supply of small asteroids in the neighbourhood of Mars and their rate of orbital transfer to Earth-orbit crossing types and subsequent losses through collisions and perturbations. There is the question whether the asteroid supply near Mars is well enough established.

B. Donn and G. W. Sears (**20a**) discuss the crystal growth of cometary particles and suggest that solid particles with filamentary structures should form. Such particles would facilitate successive aggregation into large units. In a later paper (in press) Donn extends his discussion of the origin of icy nuclei and introduces relevant data concerning the compaction of snow.

K. P. Florenskoi and I. T. Zotkin (**22**) give an excellent summary of the observational data now available concerning the 1908 Tunguska fall in Siberia. They find strong evidence that the air explosion was caused by the nucleus of a very small comet. The conclusion requires that the cometary nuclei have a weak structure, crumbling on entry.

S. L. Miller (**25**) discusses the occurrence of gas hydrates in the solar system and expects mixed hydrates of methane, carbon dioxide and ethane in the nuclei of comets. He finds that the chemical state of ammonia will depend critically upon the circumstances of the formation of the nuclei.

Spectroscopy

The most outstanding progress in cometary spectroscopy achieved during the past three years has been connected with a larger application of higher spectral resolution. The first high-dispersion spectra (18 Å/mm and 27 Å/mm) were taken by J. L. Greenstein at the coudé focus of the 200-in. reflector at Mount Palomar in 1958 (Comet Mrkos 1957 *d*), already reported in the Report for the Berkeley meeting. Since then, other high-resolution spectra have been obtained at Palomar for the Comets Seki-Lines 1962 *c* (in press), Humason 1961 *e* (**46**), Ikeya 1963 *a* (publication being prepared) and at Mount Wilson of Comet Wilson-Hubbard 1961 *d* (details not yet published, see note in *Trans. IAU* **11B,** 232, 1961).

We have a second source of high-resolution spectra of comets since 1960 in the coudé spectrograph of the 193-cm reflector at the Haute-Provence Observatory. Spectrograms published include those of Comets Burnham 1959 *k* (**39, 55**), Encke 1960 *i* (**49**), Candy 1960 *n* (**32, 33**), Wilson-Hubbard 1961 *d* (**41**), Humason 1961 *e* (**40**), Seki-Lines 1962 *c* (**58**), Honda 1962 *d* (**35**), and Ikeya 1963 *a* (**43**). Spectra of higher dispersion of Comets Humason 1961 *e* and Seki-Lines have also been described quite recently by astronomers of the Radcliffe Observatory (**59, 60**).

High resolution of cometary spectra brings several advantages. In the first place there results an improved resolution of the rotational structure of the bands. Not less important is an easier detection of new emission lines, or bands of lower intensities otherwise blended by the unresolved stronger emissions. With lower dispersion the line- and band-emission is very often only partly detectable against the strong background of the continuous emission. Connected with the high spectral resolution is also a higher special resolution.

There now follow a few brief comments about the spectrum of each comet which has been investigated with higher dispersion; these may give the reader an indication of the chief results obtained.

Comet Mrkos 1957 *d*. Greenstein and Arpigny (**45**)

Dispersion applied: 18 and 20Å/mm; heliocentric distance at time of observation $r \simeq 0{\cdot}6$ A.U. spectrum range, 3800–6800 Å. Continuous spectrum strong; sharp on tailward side from nucleus; Na D-lines extremely strong, brightest 2000 km Sunward, tailward extension 50 000 km, Sunward only 12 000 km. [OI] 6300 Å present, far tailward extension. CN (0,0) and (0,1) bands in R branches fully resolved, P branches partly. C_2 and NH_2 dominate visual

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region, bands being largely resolved; trace of $C^{12}C^{13}$ (0,1) present; C_3 group weakly present; 6 stronger unidentified lines recorded.

Comet Burnham 1959 *k*. Dossin, Fehrenbach, Haser, Swings (**39**)

Dispersion: 19 to 78 Å/mm; $r = 0{\cdot}77 - 1{\cdot}09$; range, 3000–8900 Å. Continuum very weak and narrow. R branches of CN (0,0), (0,1) completely resolved. OH (0,0) stronger than NH (0,0), C_3 strong; both CH systems show great detail, CH^+ system appears with six lines of (0,0) band. Many effects of varying radial velocities. Behaviour of spectrum from $r = 0{\cdot}77$ to $r = 1{\cdot}09$ normal.

Comet Encke 1960 *i*. Malaise (**49**)

Dispersion 80 Å/mm; $r = 0{\cdot}78 - 0{\cdot}69$
Very weak continuum, strong C_3, must be very rich in C_3.

Comet Candy 1960 *n*. Andrillat and Malaise (**33**)

Dispersion 39 Å/mm; $r = 1{\cdot}15 - 1{\cdot}10$; range blue-violet. Some continuum but narrow, intensity ratio C_2/CN abnormally weak, NH stronger than OH, CH well marked.

Comet Wilson-Hubbard 1961 *d*. Dufay and Baranne (**41**)

Dispersion 50 Å/mm; $r = 0{\cdot}425$; range 3800–6200 Å. Na D-lines very intense, intensity ratio $D_2/D_1 = 2$, C_2 partly resolved, NH_2 well present, C_3 extremely weak, region of CN under-exposed. According to Deutsch (see *Trans. IAU* **11B,** 232, 1961) [OI] red lines present, tailward side twice as strong as Sunward side.

Comet Humason 1961 *e*. Greenstein (**46**)

Dispersion 180 Å/mm; $r = 2{\cdot}6$; range 3100–5100 Å. CO^+ tail band very prominent, Baldet-Johnson system weakly present, N_2^+ strong, CO_2^+ present, OH^+ probably present; CN, C_3, CH very weakly present (compared to CO^+), intensity ratios of the neutral molecules as normally for large *r*.

Warner and Harding (**59**)

Dispersion 86 Å/mm and 320 Å/mm; $r = 2{\cdot}0$; range 4000–5000 Å. Measurements of CO^+ in good agreement with Greenstein's. Authors point to particular and unexplained rotational structure of CO^+ bands. Trace of CH^+.

Comet Seki-Lines 1962 *c*. Swings and Fehrenbach (**57**)

Dispersion 10 Å/mm; $r = 0{\cdot}55 - 1{\cdot}01$, range CN strongest. P branch of CN (0,0) for the first time widely resolved, OH very weak, Na strong at $r = 0{\cdot}55$, [OI] 6300 Å present.

Warner (**60**)

Dispersion 31 Å/mm; $r = 0{\cdot}51 - 0{\cdot}41$; range 3800–6800 Å. Continuum present, Na very strong, [OI] 6300 Å measured. Author points to abnormal intensity ratio $D_2/D_1 = 2{\cdot}5$.

Comet Honda 1962 *d*. Bretz (**35**)

Dispersion 19·4 and 39 Å/mm; $r \simeq 1$; range 3500–5000 Å,
Present CN (0,0), (0,1), C_3 4050 Å, CH 4310 Å, C_2 (1,0) (2,0).

Comet Ikeya 1963 *a*. Fehrenbach (**43**)

Dispersion 20 and 40 Å/mm; $r = 0{\cdot}73 - 0{\cdot}90$; range 3800–5000 Å. Continuum extremely weak. Order of intensity for main band systems C_2(50), CN (40), CH (20), C_3 (20), CH^+ (2). OH very weak. Isotopic bands of C_2 (1,0) present: $C^{13}C^{12}$, $C^{13}C^{13}$. CN (0,0), R branch completely resolved, P branch partly. C_3 excellently developed. Both systems of CH in a few rotational lines clearly present, also CH^+ relatively intense, NH very weak.

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Much interest centres in the appearance and behaviour of the forbidden [OI]-lines in cometary spectra. For well-known reasons the lines are not easy to observe. P. Swings (**56**) has published a survey of our present knowledge concerning the observational results, of which follows a short extract.

[OI] *emission in Cometary Spectra*

Comet Bester 1948 I. Range of heliocentric distances covered by observation $r = 0{\cdot}8 - 1{\cdot}3$. Green line always intense, red line absent or very weak, maximal intensity near nucleus, intensity gradient smaller than for CN.

Comet van Gent 1941 *VIII*. $r = 1{\cdot}55 - 1{\cdot}25$. Green line intense, red line absent. Intensity comparable to C_2 (0,0)-band or even CN (0,0) band. Later, below $r = 1{\cdot}26$, less intense.

Comet Encke 1947 *XI*. Green line more intense than the red.

Comet Cunningham 1941 *I*. $r = 2{\cdot}24 - 0{\cdot}48$. Red line more intense than the green.

Comet Arend-Roland 1956 *h*. $r = 0{\cdot}56 - 1{\cdot}15$. Red line more intense than the green line. At $r = 1{\cdot}15$ both equal.

Excitation, ionization

(*a*) *Excitation*

In hetero-nuclear compounds like CN, NH, CH etc., pure rotational and vibrational spontaneous transitions are permitted; contrary to this, such transitions are forbidden in homonuclear molecules like C_2. As was pointed out long ago (**67a**), this circumstance explains in principle the most striking differences observed between the band structure in C_2 on one side and that of CN, CH, NH etc., on the other side. Another factor which also comes into play as a first order effect in influencing the band structure in comets is the variation of the exciting solar radiation with decreasing or increasing heliocentric distance r (**67b**). The details of these effects are so well known that we need not to repeat them here. When studying the band structures under higher dispersion, in order to find a complete understanding, it becomes further necessary, as was first shown by Swings (**66**), also to take account of the fact that the Fraunhofer spectrum has numerous maxima and minima originating from lines and blends of lines. It is not difficult to recognize that this small-range unevenness cause irregularities in the excitation of the branch series of a molecular band. Since the time when the dependence of the band profiles on the parameters mentioned had been cleared in principle, there have been undertaken many attempts to represent the observational profiles as far as possible quantitatively, beginning with the first papers of Hunaerts (see (**64**) and references there). It is evident that knowledge of the real cometary rotational profiles depends effectively on the resolution attained in the spectra. Adequate theoretical treatments are laborious because of the complicated quantum structure of molecules. P. Swings gives, in a new summary report ('Recent Progress in Cometary Spectroscopy' in press), an excellent survey of the present situation and of the newer achievements based on the new high-resolution spectra. C. Arpigny (at the California Institute of Technology, Pasadena) writes that he has investigated the rotational structure of the violet CN (0,0) band from a new point of view (compared with earlier works of this kind), avoiding the usual assumption of a Boltzmann distribution in the ground state by solving the steady-state equations (which describe the resonance fluorescence) by taking into account from the beginning the presence of absorption lines and blends in the exciting solar spectrum. This procedure is certainly very laborious, but represents progress in the method. With reference to this work the writer has found it difficult to make a judgement about the accuracy really reached and the extent of the agreement with the observed spectrum. There exist, in his opinion, two serious factors of uncertainty which have not been mentioned. The first factor concerns the circumstance that in each spectrum we are always receiving light from

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molecules with a certain 'age' distribution; in other words, we have to deal with an inhomogeneous distribution over the rotational levels, the more so the nearer the comet has approached the Sun. The second uncertainty concerns the f-values with which the frequencies of the fluorescence transitions are computed. The currently used figures are all quantum-mechanical approximations and their accuracy can only be roughly estimated. The writer has recently pointed out (*Icarus*, in press) that the circular symmetry of the heads of comets in C_2 and CN, still observed at heliocentric distances as small as $r = 0{\cdot}5$, can probably not be brought into agreement with the currently used f-values of the violet CN– and C_2– Swan bands (the writer is at present investigating this question as exactly as possible). Light pressure should already deform the heads appreciably at such a distance from the Sun.

Discussion about the appearance of the forbidden [O I] lines in the spectra will certainly play in the near future, an important role, concerning excitation in comets; its explanation will very probably add much to our knowledge of the conditions in cometary atmospheres. As regards investigations in this direction we have to mention so far only two papers—if we disregard occasional brief speculations about the problem. In connection with the summary by Swings of our present observational knowledge concerning the presence and intensity of two lines in different comets (mentioned earlier under the heading 'Spectroscopy'), L. Rémy-Battiau (**65**) has next investigated whether there exists any correlation between solar phenomena (bright solar flares, relative Sunspot numbers), terrestrial phenomena (geomagnetic indices, aurorae) and the occurrence and variations in intensity of the lines. No correlation of any kind was found. The relative intensities of the two lines, on the basis of the two mechanisms fluorescence and electron collision, were then investigated. No indications in favour of either process have become apparent. Excitation by proton collision is not regarded as likely. This points to the possibility that an ion re-combination according to the symbolic equation $O_2^+ + e \rightarrow O^* + O^{**}$ (e: electron; O^* and O^{**}: excited O atoms), or the photo-dissociation of molecular oxygen to excited atoms, may provide the solution. A more definite attitude is taken by Biermann and Trefftz (**63**) who also deal extensively with this question. These authors find 'that the excitation must predominatly take place while the oxygen atom is formed by photo-dissociation'. It is not possible to explain in a few sentences how the authors arrive finally at the quoted statement. They regard, as one argument of weight, the observation that the [O I] lines show a much slower intensity gradient in the direction to the tail than the emission of any other neutral particle, and it is concluded that this fact speaks against an excitation depending on density. The two papers mentioned have certainly laid the foundation for further discussions of the problem, but it cannot be said that the solution has been found.

(*b*) *Ionization*

The problem of ionization in comets was long regarded by many as being solved with the recognition of the existence of a 'solar wind', and with the possibility of a transfer of charge from the solar protons to the cometary gas particles. When this source of charge-transfer was first discussed, there was also given, however, a warning not to regard this explanation as conclusive (**67a**). To reconcile the large extension of the heads (with their neutral particles) with the appearance of the tail-ions very close to the nucleus, there remains only the explanation that the ionization occurs by a process within the atmosphere close to the nucleus, and is limited to this region. All particles which escape this process remain neutral. A few years ago the writer (**67d, 67e**) came to the conclusion that the ionization does not depend directly on an outside influence but must be intrinsic to the cometary atmospheres themselves. We have to deal with a yet-unknown process limited to the vicinity of the nucleus.

In a recent paper by L. Biermann and E. Trefftz (**63**), of which the writer has obtained knowledge by a preprint copy, it is suggested that the tail-ions, as in particular CO^+, owe their appearance to chemical reactions between invisible primary ions due to photo-ionization and other molecules. A typical 'model' reaction expressed in chemical symbols is, for instance,

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given by: $H_2^+ + CO_2 \rightarrow CO^+ + H_2O + 1{\cdot}0$ eV. This reaction is (with 1 eV) exothermic. Apparently, the authors consider the restriction of the ionization to the vicinity of the nucleus, and also the short time-scale of the ionization as determined by the writer (**67f, 67h**) from fluctuations in the CO^+ production, as determined and explicable by higher atmospheric density. An old argument against a weight of chemical reactions within the atmospheres (beside the photo-chemical primary process) put forward by the writer (**67c**) is based on the very different 'rotational temperatures' of CN on one side and C_2 on the other side that are always observed. We may add, in this connection, the 'visible' influence of increasing excitation frequency (with decreasing heliocentric distance r) on the rotational temperature of the CN molecules.

In addition to the argument just mentioned there are still other indications which do not favour the importance of chemical reactions. Since these reactions depend strongly on particle densities it is hard to understand why, in general, weak and bright comets (for the same heliocentric distance r) are so homogeneous in spectral composition. One may also mention, as difficult to explain on the basis of the chemical theory, the comets with strong CO^+ tails at large heliocentric distances (Comet Humason 1961 *e*, Comet Morehouse 1908 III). Although the strong CO^+ points to a high abundance of CO or CO_2, the weakness of the other emissions and the large heliocentric distances do not support the assumption of a particularly dense atmosphere. It should also not be overlooked that the tail-ions make their appearance always in front of the nucleus (**67f**). It is not easy to see how the chemical theory can explain this typical lack of symmetry.

It may be mentioned that our belief in the negligible importance of chemical reactions in cometary atmospheres does not imply the unimportance of such processes inside and on the surface of the solid material of the nucleus.

The 'wide-field' ionization (and also dissociation) of typical cometary particles as CN, C_2, etc., appears to have a very low probability. All particles which escape ionization in the active zone near the nucleus are able to travel to large distances from the nucleus having ($r = 1$) an average life time τ of the order of 10^6 seconds. The writer (**67g**) concluded from this fact that the ionization of cometary particles by the 'solar wind' corpuscles is completely negligible, and that the proton density in the corpuscle stream must be below 10^1 cm^{-3}.

Models of the coma

The isophotes of a dust-poor coma (mainly CN and C_2) are essentially circular and symmetrical about the nucleus. For isotropic ejection from the nucleus, idealized as a point, and with a single or sharp velocity v_0 of the particles, and no particle decay, the density decreases with the distance ρ from the nucleus as ρ^{-2}, which gives a law of surface brightness ρ^{-1}. The latter involves, of course, the condition of a low optical thickness, which is certainly never violated by C_2 because of the distribution of the molecules over a large number of quantum levels, and which will become critical for CN only for the brightest objects. The molecules will suffer dissociation and/or ionization with a probability τ_0^{-1} sec^{-1}, τ_0 being the average life-time until ionization or dissociation. If $v_0 \cdot \tau_0 = \rho_0$ is not much larger than the observed radius ρ', the model demands the introduction of a decay factor exp $(-\rho/\rho_0)$. Expressions for the law of surface brightness, according to the density law $D(\rho) \sim \rho^{-2}$ exp $(-\rho/\rho_0)$ have been given by L. Haser (**68**) and K. Wurm and Balazs (see *Icarus* **2,** in press). Haser has outlined in his paper a slightly more complicated model, in which he postulates that the emitting molecules originate from invisible parent molecules by dissociation, the latter having also a finite and perhaps not-negligible life-time τ_1 and an expansion velocity v_1, which enable them to travel to a distance $\rho_1 = v_1 \cdot \rho_1$ from the nucleus before being dissociated.

F. D. Miller (**70**) had discussed the possibility of representing the observed dependence of

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surface brightness on nuclear distance by mathematical models. Concerning the observations, he considers a mean C_2 surface-brightness curve derived from three comets (1955 *e*, 1955 *g*, 1959 *k*) as typical for the ρ-dependence; this mean curve has a proportionality to ρ^{-1} up to $\rho = 20\,000$ km and is becoming more proportional to ρ^{-2} at greater distances. The limit of ρ is equal to 110 000 km in the representation. The author considers that it is not possible to obtain a satisfactory fit with either of the two models developed by Haser. The matter has later been dealt with again by O'Dell and Osterbrock (**71**) who judge the situation less critically.

These authors add further observational material to that of Miller, i.e. their own photometric measurements of the surface brightness of Comet Seki-Lines 1961 *f*. They accept Miller's mean surface-brightness distribution, and find that the same can be satisfactory represented by a Haser model with $\rho_0 = 10^{4\cdot 93}$ km and $\rho_1 = 10^{3\cdot 98}$ km.

The most important parameter for a coma model is certainly $\rho_0 = v_0 \cdot \tau_0$. The writer has dealt recently with the numerical value of ρ_0 in several papers (**73a, 73b, 73c**) and advocated first $\rho_0 = 10^{5\cdot 5}$; this was later replaced by $\rho_0 = 10^6$. The first was derived from the expansion and average life-time of spherical halos of CN and C_2 described by N. T. Bobrovnikoff (**19**) in his large paper on Comet Halley 1910. B. A. Vorontsov-Velyaminov (**72**) made it clear that comets (at heliocentric distances $r = 1$) can have coma radii as large as 10^6 km and perhaps more. The writer found also plates of comets (**73c**), which prove this. Radii of the coma as large as 10^6 km demand a constant ρ_0 of the decay factor of the same order. Since the expansion velocity v_0 is of the order 1 km/sec, the average life-time of the head molecules such as CN and C_2, must therefore be of the order of 10^6 seconds for $r = 1$. The expansion velocity $v_0 = 1$ km/sec represents an average of several values between $v = 0\cdot 5$ and $v = 1\cdot 8$ determined by Bobrovnikoff.

If one intends to derive a fairly exact value of ρ_0 from steady-state conditions after the method of O'Dell and Osterbrock (**71**), one needs the distribution of surface intensity for a much larger range of ρ than the authors have used. The most reliable method of obtaining an approximately correct ρ_0 is certainly the study of well-separated halo formations.

C. R. O'Dell and D. E. Osterbrock also publish in their paper the absolute density-distribution of the C_2 molecule in Comet Burnham 1959 *k* and Comet Seki-Lines 1962 *c*. The density amounts to $10^2\,\text{cm}^{-3}$ near the nucleus at $\rho = 10^3$ km but has decreased to $10^{-2}\,\text{cm}^{-3}$ at $\rho = 70\,000$ km.

V. Konopleva (**69**) has constructed isophotes for both the photographic and photovisual ranges for five different comets (1948 I, 1948 IV, 1952 III, 1955 IV, 1955 V) and has tried to derive from this material the volume-luminosity law ρ^{-n}. She finds values of n between $1\cdot 5$ and $2\cdot 1$.

Structure of tails

While the theory of type II tails does not appear to have difficulties in principle, the situation for the type I ion-tails is quite different. The composition and structure of the ion-tails present two main problems: (*a*) the creation of the ions from neutral particles near the nucleus, and (*b*) the kinematics and the dynamics of the tail material. All authors who have tried in recent years to develop a general theory of the plasma tails (**74, 75, 6, 79, 80**) started from the beginning with two assumptions: (α) that the tail-ions are formed by a bombardment of 'solar wind' protons (charge-transfer ionization), and (β) that the proton stream is also responsible for the acceleration of the tail-ions (momentum-transfer by Coulomb interaction, or more likely by the magnetic fields of the solar corpuscle stream). The writer believes that the first assumption is now regarded by most authors as invalid, and that new research to explain the ionization has to be started. The validity of assumption (β) does not necessarily depend on that of assumption (α).

The first to point to the possibility of an interaction between magnetic fields embedded in

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solar corpuscle streams and the cometary ions including a momentum-transfer to the latter was H. Alfvén (**74**). M. Harwit and F. Hoyle (**80**) have recently tried to give Alfvén's ideas a more precise and semi-quantitative form; their results, when confronted with well-established kinematic and structural properties of the tails, are in the writer's opinion not very convincing. Avoiding all mention of less spectacular features, we refer only to the difficulty which the theory has of explanating the three-dimensionality of the fan-shaped ray structure. The latter requires magnetic lines of force with random orientation perpendicular to the stream velocity, which evidently contradicts the often-observed regular and undisturbed development of long, narrow and straight streamers or rays over hours or even days.

The belief by many authors that there exists a strong interaction between solar plasma streams and cometary atmospheres rests widely on the conviction that a correlation between solar activity and increased cometary activity has been proved. The astrophysicists at the Max-Planck-Institut, Munich, have in particular paid attention to this problem (**75, 81**). Rh. Lüst (**81**) has recently investigated whether the gaseous, ionized cometary tails show also pronounced activity and fast changes in structure during periods of low geomagnetic disturbances and general low solar activity. Four comets were found which had ionized tails showing rapid and continuous changes of structure during extended periods of extremely low geomagnetic activity. It is concluded that, even during these times, the Sun is emitting still enough solar particles to maintain a strong interaction with the cometary particles. In the same paper attention is directed to a correlation between strong geomagnetic disturbances and eruptive bursts in Comet 1899 I. In another publication Rh. Lüst (**81c**) points to Comet Abell 1953 *g*, which showed also an active ionized gas tail during a period of extremely low geomagnetic activity in 1954, the year of the last sunspot minimum. Lüst (**81b**) has also investigated a set of Mt. Palomar Schmidt-plates of Comet 1957 *d*. Velocities and accelerations were derived for different parts of the tail and for special structures such as the 'edge' visible on August 23–25, while the comet was at high heliographic latitude. About further activity in comet research at the Max-Planck-Institut, L. Biermann and Rh. Lüst write as follows. 'The dynamical interaction between the solar plasma and the cometary gas was studied by B. Brosowski, H. U. Schmidt, and L. Biermann (**76**) who gave particular attention to the influence of charge-exchange in the equation expressing the balance of momentum and energy. A statistical study of the properties of plasma tails of comets, that have appeared since 1892, was begun by D. Antrack, L. Biermann, and Rh. Lüst.'

It seems rather certain that the formulation of a successful dynamical theory still needs many hints from observation, and a better knowledge of the real structure and the kinematical properties of the tail material. There is the gradual displacement (closing-in) of the tail streamers to the tail axis first elucidated by W. Lehmann and the writer (**84**) from a series of plates of Comet Brooks 1911. The writer has made clear (**85**) that this effect depends at least partly on a decrease of the velocity of ejection with time. The suspicion was voiced (**5**) that, in addition, there appears a force which accelerates the ions in the direction of the tail axis more or less perpendicularly to the prolonged radius vector. It seems now that E. J. Öpik (**83**), with the analysis of the orbit of a condensation observed by Bobrovnikoff in the tail of Halley's Comet, has proved the real existence of such a transverse force. The author finds that the radial and transverse forces are of approximately the same magnitude, namely equal to 50 times the solar gravitation at the place of the comet. The initial velocity is determined as + 28 km/sec (radial) and + 26 km/sec (transverse, in the direction opposite to the orbital motion). Öpik's results must be regarded as highly important.

There have been written two papers concerning the stability of the tail axes. D. Malaise (**82**) determined the angle between the tail axis and the radius vector of Comet Burnham 1959 *k*. He found from 26 photographs an oscillation between + 17° ('behind' the radius vector) and − 9°·7. There has, however, to be raised the question whether the tail axis was always defined

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in accord with the same principle on all the plates. The writer (**86**) proposed in a recent note to define the tail axis as that direction to which the tail rays are 'closing-in' and not simply by means of the longest streamers on the plates. It remains an open question whether the tail axis defined in this way maintains a stable position relative to the radius vector or not. In the paper just mentioned the writer shows that the direction of the tail axis as defined is determined by the same forces which regulate the outflow of the tail-ions from the vicinity of the nucleus.

Laboratory Work

E. A. Ballik and D. A. Ramsay showed a few years ago that the ground state of the C_2 molecule is not the lower state of the Swan system $^3\Pi_u$ but a $^1\Sigma_g^+$ state which lies 610 cm^{-1} below the former. A full discussion of this work has recently been published (**96a**). The same authors have also given an extension of the Phillips system (**96b**) and summarized our present knowledge of the C_2 molecule.

G. Herzberg and J. W. C. Johns (to be published) have investigated the absorption spectrum of CH in the vacuum ultra-violet. The existence of a Rydberg series has been established which leads to an ionization potential of 10·64 eV and incidentally to a dissociation energy of CH^+ of 4·09 eV.

The well-known 4050 Å group of cometary spectra first observed by G. Herzberg (**104**) in the laboratory and shown to be due to the C_3 radical by A. E. Douglas (**99**), has been re-investigated in absorption in the flash photolyses of diazomethan (**108**). In the earlier work of Douglas only the most prominent band at 4050 Å was analysed; the present authors believe that they now have a full analysis of the spectrum. For two reasons the spectrum is particularly complicated: (*a*) The bending frequency in the ground state is very low (65 cm^{-1}) giving rise to a large number of bands even at room temperature; and (*b*) vibronic interaction in the excited state leads to large Renner-Teller splittings which makes it impossible to recognize simple progressions.

The NH_3 molecule is presumably the parent molecule of both the NH_2 and NH observed in comets. It has an absorption spectrum starting at about 2200 Å. This spectrum has been very fully analysed during the last two years at Ottawa by A. E. Douglas and J. H. Hollas (**100**) and A. E. Douglas (**101**).

Also the spectrum of CH_3 has been more fully analysed in Ottawa (**107**); its absorption at 2150 Å is quite diffuse, indicating that its life-time in comets (where we have very probably to expect it) cannot be long.

According to G. Herzberg (**107**) and G. Herzberg and J. W. C. Johns (to be published), CH_2 does show strong pre-dissociation in the strongest absorption band at 1415 Å. Concerning the structure of the molecule, this work has established that it is linear in its lowest triplet state and bent in the lowest singlet state, and that the triplet state is slightly below the singlet state.

The far ultra-violet spectrum of H_2 in the range 1000–800 Å has been investigated by G. Herzberg and A. Monfils (**106**) as well as by A. Monfils (**112**), and independently by T. Namioka (in press).

The far ultra-violet absorption spectrum of H_2O near 1250 Å has been investigated under high resolution by J. W. C. Johns (**110**) who also included D_2O in his study.

Of the work done at Ottawa we mention also a number of molecules which may perhaps become of importance in cometary research in the future: Si_2 (**122**), PH (**111**), HS (**115**), NCO (**98**), HNO (**115, 117**), HCO (**118**), HNCN (**109**). M. Rigutti and F. Drago (**119**) published an analysis of the (2,0) and (3,1) bands of the red CN system.

P. Felenbok (**102**) carried through a rotational analysis of the (0,6), (0,7), (0,8) and (1,9) bands of the $B^2\Sigma - A^2\Sigma$ system of OH and of the (0,8), (0,9), (0,10), (0,11), (1,9), (1,11) for the same system of OD. Franck-Condon factors for five OH and three OD transitions were

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computed. New bands of the $C^2\Sigma - A^2\Sigma$ system of OH have been found and the rotational structure of the transitions (0,9) and (1,9) has been analysed.

L. Herman and P. Felenbok (**103**) published a photometric study of the bands of N_2^+.

Space investigations and comets

Until a few years ago, interest in comets was mainly connected with their random, erratic behaviour, when compared to the other objects of the solar system. It is now well recognized that when they are better understood they may become very important for other areas of research in the solar system. The orbits of comets extend through the entire domain of the solar system, touching the solar corona and reaching distances many thousands of astronomical units from the Sun. Physical observations of comets are already frequently being made out to the orbit of Jupiter and sometimes even beyond. Cometary research at present receives the highest stimulation by the potential value of comets as space probes. Using exclusively data from cometary observations, the writer was able to show several years ago (**67a, d, e**), before corresponding data from artificial space probes had become available, that the flux of the particles in the 'solar wind' was constantly much too low to be able to ionize cometary particles such as CN, C_2 and others, and that the observed ionization in cometary atmospheres does not depend at all directly on outside influence. Already as early as about fifty years ago, some authors suspected the presence of magnetic field in the tails, because of the filamentary structure of the gas tails (**125, 130**). Today many authors believe that these fields are identical with the interplanetary magnetic field imbedded in the 'solar wind'. Because of the extremely high masses of gas and dust which the comets are 'releasing' when near perihelion, it seems improbable that any artificial space probe with a gas release function will ever be able to compete with them.

From the earlier sections of this Report, it should have become clear how far the lack of understanding of cometary phenomena goes, and which questions are constantly being raised. There is no lack of suggestions as to how artificial space probes and rockets may be used to contribute to the physical study of comets. Valuable and comprehensive reports have been prepared by P. Swings (**131**) and B. Donn and W. M. Alexander (**128**), special proposals were published by L. Biermann, R. Lüst, Rh. Lüst, and H. U. Schmidt (**126**), H. C. Corbin (**127**) and I. C. Lair (**129**).

Three different types of experiments are generally considered:

(1) experiments with rockets releasing gases such as NH_3, CO_2, H_2O, etc, or vapours of Ca, Sr, Ba, and other 'metallic' elements;
(2) experiments with an orbiting artificial nucleus;
(3) comet probes going through or near a comet.

The gases and vapours in the release experiments under (1) should be (as far as possible) exposed to pure solar effects only. The objectives of these researches concern in the first place the detection of the 'parent' molecules of the radical CN, C_2, CH, NH, NH_2, and OH which appear always within the comae of the comets, and the origin of which has remained obscure; as parent compounds these are suspected NH_3 for NH_2 and NH, H_2O for OH, CH_4 for CH, etc. The suspected parent compounds are without a spectral emission in the spectral range which is accessible from the ground, because of the particular excitation condition in comets (fluorescence excited by solar light). An ultra-violet spectrograph in a comet probe (according to (3)) may possibly also lead to the detection of the parent compounds. As the first step in the release experiments (concerning the experiments serving comet research) releases at heights of a few hundred kilometres are planned, although disturbances by atmospheric constituents are to be expected. Sodium-cloud experiments already carried out indicate that bi-molecular recombinations are negligible; however, exchange and abstraction reactions will certainly be important when more complex molecules are involved.

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The next step beyond the simple release experiments (which may, however, reveal themselves to be not so simple in respect of adequate technique and of the technique of observation) would be the launching of an orbiting artificial nucleus. First estimates predicted for a 'Whipple icy conglomerate nucleus' of one ton give a life-time of several days. The predictions made about the brightness of the coma and tail of such a comet, and whether they are likely to be observable or not, are rather contradictory. E. J. Öpik (**14**) finds that artificial comets, because of the fast diffusion of the material into free space and the particular light distribution caused by this diffusion, are at all prohibitive. The writer is of the opinion that Öpik's conclusion is very probably correct, if we have to deal with a nucleus of a 'Whipple mixture' for which the 'visible' particles have yet to be created by a photo-chemical dissociation. The often-mentioned 'snow ball' comet ($CO_2 + h\nu \rightarrow CO^+ + O$) has certainly no chance at all of becoming visible, since the time-scale of the CO_2 or CO ionization is of the order of 10^{-6} sec^{-1} (see **67h**).

We do not intend to deal here longer with the third experiment, since its realization is certainly not a subject for the near future. However, if the performances of these probes are as effective as has been suggested, their application may really bring—as has been said—the breakthrough in our knowledge of the comets.

PART II. ADMINISTRATIVE REPORT

In the Report of Commission 15 in *Trans. IAU* **11B**, 1961 (Berkeley meeting), various special suggestions for the promotion of cometary research, and comprising all special branches, were mentioned; these suggestions and recommendations may also be considered as a guide for the near future. We shall not repeat them here. However, a few additional comments may not be out of place.

Those who wish to obtain closer information about present-day research in cometary spectroscopy (Suggestions no. 2 and no. 3) and its requirements are informed that they can find it in P. Swings' very recent summary report (in press). Because of its importance it cannot be emphasized too much that particular attention—when the quality of the instruments used allow it—be paid to the behaviour of the forbidden [O I] lines, and to obtaining data about the distribution of the surface brightness in the lines.

Monochromatic photometry (Suggestion no. 5) is growing only slowly in its application although at the stage now reached in the physical study of comets monochromatic isophotic contours, or monochromatic photo-electric tracings, are rather important for further development. We recall that 'monochromatic' here also includes the pure continuous emission. The continuum seems to become best accessible either to the red of the C_2 (0,0) band or between the bands of OH and NH in the ultra-violet. It should not be difficult to obtain monochromatic pictures in the D-lines for comets with small heliocentric distances. The shape of the Na-coma is expected to be very different from that in the coma bands such as C_2 and CN.

The study of type I tails needs series of pictures of short exposure. Of very high value would be CO^+ monochromatic pictures with high resolution in the vicinity of the nucleus. Since in this region the tail streamers certainly have a rapid movement the exposures should be short, not exceeding a few minutes. Through the courtesy of Sir Richard Woolley, director of the Royal Greenwich Observatory, the writer has on loan at present the excellent photographic material for Comet Morehouse 1908 which was obtained at Greenwich with the 30-inch telescope. The material comprises 156 individual originals and these contain several series of five to nine photographs taken in one night. From these photographs we can expect valuable information concerning the kinematics of the plasma tails of comets. Work on the lines done recently by E. J. Öpik (see the section on the Structure of Tails above) on condensations in the tail of Comet Halley 1910 will frequently be possible with the Greenwich material.

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It has been suggested by several colleagues that the possibility of making generally available copies of good photographs of comets from various observatories should be discussed in Hamburg.

K. WURM
President of the Commission

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ADDENDUM
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