15. COMMISSION POUR L'ETUDE PHYSIQUE DES COMETES

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I. NARRATIVE REPORT

A. Introduction

The form of this Draft Report follows the practice of the 1964 Report. The first is a Narrative, briefly presenting progress as evaluated by the writer. Second is a short Administrative Report including results and plans for cooperative activities. Third is a comprehensive Bibliography, with extremely short abstracts. The writer is greatly indebted to the members of the Commission who have provided him with important assistance in the preparation of this report, particularly C. Arpigny (spectroscopy), G. Herzberg (laboratory work), and V. Vanýsek and B. J. Levin (Slavic languages). The writer, however, takes complete responsibility for the accuracy and relevancy of the contents.

A major event was the 1965 sun-grazing comet (Ikeya-Seki, 1965*f*), whose perihelion distance was only 0·008 A.U. As the eighth member of the sun-grazing comet group that includes the great comet of 1882, it aroused worldwide interest and contributed valuable knowledge concerning the stability of cometary nuclei and concerning activities in and about the coma.

Another event of great cometary importance was the Thirteenth Liège Symposium devoted to the nature and origin of comets. This international symposium organized by the current President of the IAU took place in July 1965 and brought together an international group of researchers in this field.

Its proceedings and other important books and monographic articles are listed at the beginning of the Bibliography under the heading: A. Books and Monographs. The references are alphabetized under each subsection separately, and the subsections identified by capital letter, A., B., C., etc., for cross-referencing.

B. Photometry

The rapidly increasing pace of cometary photometry and its improved quality obtained by photoelectric and other methods of measurement are highly gratifying.

Here are listed contributions to magnitude measures, surface photometry, special observations, studies of brightness changes and correlations, polarization and measures in the radio and infrared regions.

At the Haute-Provence Observatory, high-resolution spectrograms have been used (Malaise 1966) to determine photometric radial profiles of CN, C_2, C_3 and CH, and a special photometer for this use is being designed.

N. Richter and W. Högner (1964, 1966) use contrast printing of positives and negatives to produce isophotes from comet photographs. An atlas is being prepared to include all bright comets.

V. G. Rijves (1964, 1965) has also developed new photometric parameters and techniques for calibrating cometary photographs and presents photometric observations. D. A. Rožkovskij (1965) describes a new procedure for photographic photometry and processes photographs of Comets Ikeya, Humason, Alcock and Kopff.

For the IQSY, S. K. Vsehsvjatskij (1964*a*, 1964*b*) makes recommendations about programs and methods of comet observation. In the same program R. B. Southworth (1966) describes the use of the 12-station satellite-tracking system of the Smithsonian Astrophysical Observatory for measuring integrated magnitudes and colors of comets and gives some results for Comet Ikeya (1964*f*).

E. Roemer continues her valuable regular reports on cometary brightness and appearances, and (1965) with R. E. Lloyd (1966) and M. Thomas (Roemer *et al.* 1966) has presented nearly 1450 observations of 75 comets. She is planning an atlas of direct photographs of comets and will analyze comet photographs of the U.S. Naval Observatory for head and tail structure.

S. Vsehsvjatskij (1964*a*, 1964*b*, 1964*c*) has published two extensions (to 1965) of his catalogue of photometric parameters of comets. For 167 comets in the catalogue, A. A. Demenko (1966) has classified their tails according to Bredikhin's types. V. Rijves (1964, 1965) presents photometric measures for several comets.

Isophotes of the heads (*h*) and/or tails (*t*) of comets have been made by the following investigations: A. A. Demenko (1964) and D. O. Mokhnach (*t*, Seki-Lines, 1962*c*); O. V. Dobrovol'skij and H. Ibadinov; and V. P. Džapiašvili and G. N. Salukvadze (1965) (*h* and *t*, Arend-Roland, 1957 III); G. N. Salukvadze and V. P. Džapiašvili (1966) (*h* and *t*, Mrkos, 1957 V); G. K. Nazarchuk (1965) (*h* and *t*, Arend-Roland with theory for stream formation); L. M. Genkina (1964, 1965*a*, 1965*b*, 1965*c*) (*h*, 1961*e*, 1963*i*, 1964*h*, and P/Kopff); T. A. Polyakova and G. S. Romashkin (1965) (*h*, 1965*b*, 1965*c*, 1964*h*, 1964*g*); and E. E. Khachikian and R. A. Epremian (1966) (*h*, 1963*e*). S. Grudzinska (1965) has investigated photometrically 1963*a* and 1963*b*.

Photoelectric photometry has been carried out by J. Bouska and P. Mayer (1966) for 1964*h* (Everhart), in the UBV system with a special filter, and by Mrkos, Tremko and Vanýsek (1966) for 1966*b* (Kilston) and 1966*c* (Barbon). On 1964*f* (Ikeya) N. A. Kovar and R. P. Kovar (1965*a*, 1965*b*) have made photoelectric scans for CN, C_3, C_2 and CH.

The remarkable photographs by T. Hirayama and F. Moriyama (1965) of Comet Ikeya-Seki (1965*f*) with a coronograph show the tail highly curved as the comet swings through the corona. Their observations of the splitting of the nucleus are of great value. The coronograph observation by J. M. Malville and C. Evans (1966) show striking changes with time in the ratio of the D_1 and D_2 lines of Na, suggesting changes in the optical depth. V. Vanýsek (1966) made photoelectric measures in the infrared, and Z. Ceplecha and B. Valniček (1966) in the near red. The infrared measures at 1·65, 2·2, 3·4 and 10μ for 19 days by E. E. Becklin and J. A. Westphal (1966) show a calculated blackbody temperature that is nearly 50% too high for expected dust temperatures. They suggest iron or iron-like particles as the cause.

Other observations of Comet Ikeya-Seki have been reported by M. Bader and L. C. Haughney (1966) from a jet aircraft at 13 km, photographed several times; P. B. Boyce and W. M. Sinton (1966) before and after perihelion with spectra scanner; J. L. Weinberg (1966), polarization measures and Stokes parameters at λ 5300Å; and A. D. Thackeray (1965) on the split nucleus.

M. Beyer continues his long series of comet observations with the 20-cm refractor of the Hamburg Observatory. These observations of cometary brightnesses and Beyer's determination of brightness-variation parameters are particularly valuable because of their uniformity, prolonged over so many years. Results (1964, in press) for several comets show two very interesting outbursts of Comet Alcock (1965*h*). Beyer plans an index list for his measures of about 100 comets. Bertaud (1965) studied 'flares' of the Comet Schwassmann-Wachmann I.

For Comet Humason (1961*e*) C. E. Kearns and R. Rudnicki (1966) have published 28 fine photographs with the 48-inch (121 cm) Palomar Schmidt (five in yellow). They show the extraordinary changes occurring in the head and tail of this distant comet.

Correlations between cometary brightnesses and solar activity are reported by Vsehsvjatskij (1965*a*, 1965*b*) and (1964*d*, 1964*e*, 1965*c*, 1965*d*, 1966) for several comets in the last 40 years, including a correlation for P. Schwassmann-Wachmann I with solar rotation. P. Notni photoelectrically (1961) and S. Grudzińska (in press) also find correlations of cometary brightness with solar activity. Correlations with the brightness of the zodiacal light are suggested by M. Fracassini and L. E. Pasinetti (in press), and with meteorological conditions in Europe and North America by Sekanina (1964*a*, 1964*b*).

The secular fading in the absolute brightnesses of P/Encke is indicated not to exceed 1 magnitude per century by L. Krésak (1965) from maximum brightness observed at each apparition, whereas D. H. Douglas-Hamilton and the writer (Whipple and Douglas-Hamilton 1966) derive a much more rapid fading. The latter find no solar-correlated variations for P/Encke nor firm choice between a $1/\Delta^2$- and the $1/\Delta$-law suggested by Öpik (1963). J. Bouska (1965) expects P/Oterma to become unobservable after its recent orbital changes.

V. G. Rijves (1964, 1965) finds a surprisingly low value of the parameter n, $(1/r^n)$ for comets.

T. Gehrels (1966) and M. T. Martel and M. Saute (in press) made polarization measures of comets. T. Takakura *et al.* (1965) could detect no radio emission from Comet Ikeya-Seki (1965*f*) at 160 hertz.

F. Dossin (1966) found a probable comet near the Sun during the eclipse of 20 July 1963.

Questions as to the true secular rates of fading for periodic comets and possible correlations of nuclear or head luminosity with solar activity continue to remain without definitive answers, at least to the writer. Improved photometric methods and their extensive application still appear necessary.

C. Spectroscopy

The George Darwin Lecture, which was delivered by the President of our Union in 1964, was devoted to cometary spectra (Swings, A 1965). In the first part an historical resumé is given of the spectroscopic observations of comets during the hundred years that have elapsed from the first such observation of a comet in 1864 until the recent progress brought about by the use of some of the largest telescopes for cometary observations. Then a number of important desiderata are expressed and plans for the future spectroscopic work on comets are described. These concern observations from the ground as well as from balloons or aircraft, from rockets or satellites.

In two important survey papers C. Arpigny (A 1965) and (1965) has studied the Swings mechanism (resonance fluorescence excitation, including the effects of the Fraunhofer lines) in detail on the basis of the theory of the steady-state conditions. His predictions agree very satisfactorily with observed cometary spectra. He has also discussed the Greenstein effect (different relative intensities of some rotational lines in different regions of a comet), and presents (1965) a critical revision of abundance determinations in comets, with new results as well. Furthermore, he reviews the question of the forbidden oxygen lines present in the spectra of a number of comets and questions the identification of cometary [O I] lines in the cases when the green line is stronger than the red doublet ($I_G > I_R$). In this connection, a series of spectra of Comet Bester (1948 I) are being studied photometrically in Liège with a view to establishing the origin of the strong line observed at λ 5577 on these spectra. This is the only case with $I_G > I_R$ where there remains any strong doubt as to the origin of the oxygen lines. Here we should also point out an error that has slipped into the Bibliography appearing in the 1964 Draft Report: The comment 'green [O I] line present' given for reference **57** (p. 178 of the Report), which concerns Comet Seki-Lines (1962*c*) (not *e*), is wrong; only the red line λ 6300 has been identified in the spectrum of this comet.

The advantage of cometary observations with high-resolution equipment can be no better illustrated than by the result of A. S. Stawikowski and J. L. Greenstein (1964), who measured the λ 4745 line in Comet Ikeya (1963*a*) for the C^{12}/C^{13} isotopic abundance ratio. They found $C^{12}/C^{13} = 70 \pm 15$, comparable to the values for the Earth and meteorites. This result is perhaps the only direct evidence pointing (still not definitively) to a solar-system origin for comets.

Comet Ikeya-Seki, 1965*f*, the sun-grazing comet, produced some startling spectroscopic results. V. Livingston *et al.* (1966) with the McMath Solar Spectrograph at 5 mm/Å (!), identified Si, Ca, Na, Cr, Mn as well as many Fe lines in the spectrum near perihelion. The Na D lines in emission and Fraunhofer absorption show a huge displacement arising from the high velocity of the comet. Na was being ejected some 4 km s^{-1} radially from the nucleus and reached a maximum velocity of 18 km s^{-1} along the tail. J. Dufay, P. Swings and Ch. Fehrenbach (1965, 1966) at the Haute-Provence Observatory find from a preliminary study that about 90 very sharp metallic emission lines appear on the 4Å/mm spectra of 21 October. Most of these are Fe I lines, while the rest belong to Na I, Ca I, Ca II, Mn I, Ni I, and probably Al I. The Fe I lines are short, their extension being about 8 seconds of arc on each side of the central nuclear condensation. On the contrary, the Na I D lines and the Ca II H and K lines are rather long (about 25 and 60 seconds of arc, respectively). A detailed study of the excitation of these emissions has been undertaken in Liège, and it will be possible to compare the results of the post-perihelion observations with pre-perihelion spectra lent by Dr A. D. Thackeray from the Radcliffe Observatory (Thackeray *et al.* 1966). Spectroscopic material has also been lent from the Sacramento Peak and the Kitt Peak Observatories.

Low-dispersion spectra showed a weak continuum both on 13 October and 21 October 1965. A. D. Thackeray *et al.* (1966) also found that near perihelion the CN bands were weaker, compared to greater solar distance, and that the presence of C_2 and C_3 was uncertain. On 20 and 21 October 1965 G. W. Curtis and Sacramento Peak Observatory Staff (1966) observed four spectra at 2·5 Å/mm. They observed both the comet and the solar corona, and made polarization measures of the comet and photoelectric scans in Na D. These measures are being analyzed. J. M. Malville and C. Evans (B 1966) measured the Na D_2/D_1 ratio and the Na/continuum ratio near perihelion, finding rapid changes in the gas/dust ratio.

Comet Candy (1960*n*). Let us point out a note (Wyller 1962) concerning the identification of some near infrared emissions. This was published in 1962, but was not mentioned in the Draft Report of the 1964 General Assembly of the IAU. Flynn (1961) had observed strong emissions in the wavelength regions λλ 7765–7850 and λλ 8013–8070, and he had attributed these emissions to the red system of CN in spite of the large difference between these wavelengths and the expected positions of the (2, 0) and (3, 1) CN red bands. Wyller (1962) gave some arguments in favor of the identification of the observed emissions with the (3, 0) and (4, 1) bands of the C_2 Phillips system. Actually, Wyller's main argument should be revised because it used a value of 2500°K for the rotational 'temperature' of the C_2 Swan bands, whereas a recent determination of this parameter by C. Arpigny (1966*a*) indicates a value of about 5000°K. Thus, the value of J (total angular momentum quantum number) at which the intensity maxima should occur in the various branches of the Phillips bands is a factor of about $\sqrt{2}$ larger than indicated by Wyller, with the result that the wavelength coincidences between these maxima and the observed emission features is now less convincing. However, the intensity distributions are certainly very broad and only a detailed examination could settle the question of a possible contribution of the C_2 Phillips bands to the observed infrared emissions. In connection with the problem of the formation of C_2, it is important to establish whether these bands are present or not in the spectra of comets. L. J. Stief and V. J. DeCarlo (1965) suggest that the Swan bands arise from the photodisassociation of acetylene or acetylene-like molecules.

Comet Humason (1961*e*). C. Arpigny (1964) has made some corrections to Warner and Harding's (1963) discussion of their spectroscopic observations. It has been shown that an anomaly mentioned by these authors concerning the CO^+ comet-tail bands (absence of the *R*-branches) disappears when the correct line strengths are used for the various branches and when the effects of the Fraunhofer lines are taken into account in the fluorescence-excitation mechanism. At 5 A.U., F. V. Dossin (1966) finds a faint continuum at the center and emission of CO^+ N_2^+ and CN (faint).

Comet Seki (1961*f*). Y. Andrillat (1966), spectrum 3500–5000 Å, 29 Å/mm, 15 and 18 October 1961.

Comet Ikeya (1963*a*). F. D. Miller (1964), two objective-prism spectra. C. Arpigny (1966*b*) shows that the λ 4300 band of CH was excited by fluorescence. The electric dipole moment of CH appears to be about 1 Debye. He finds (1966*a*) from high-resolution spectra also of Seki-Lines (1962 III) and Burnham (1960 II) that the 'temperatures' of the rotational and vibrational distribution of cometary C_2 Swan bands are higher (5–6000°K) than earlier studies indicate and virtually independent of heliocentric distance or comet. See also Malaise (B 1966) and Grudzińska (B 1965).

Comet Alcock (1963*b*). D. Chalonge and M. Bloch (1966) find from low-dispersion spectra that scattered continuum is slightly redder than solar radiation.

Comet P/Kearns-Kwee (1963*d*). F. Dossin (1964) describes the spectrum. The theoretical paper on the C_2 Swan bands in comets by R. E. Stockhausen and D. E. Osterbrock (1965) is criticized by C. Arpigny (1966*c*) on both observational and theoretical grounds.

G. Righini (1966) discusses early observations of cometary spectra.

In his contribution to this report C. Arpigny stresses the following desiderata in cometary spectroscopy:

(*a*) Monochromatic radial profiles of the various atoms or radicals observed in comets. Dependence of these profiles and of the 'radii' of the coma in monochromatic light upon the heliocentric distance of the comet would yield invaluable information concerning the production of these atoms or radicals (Arpigny 1965, Malaise B 1966).

(*b*) Observational data on the spectral energy distribution of the scattered continuum and on the polarization of this continuum. When compared with the results of the theoretical investigations, this would shed light upon the problem of the nature of the scattering particles. See e.g., L. Remy-Battiau (1964, 1966).

(*c*) Radial profiles of the forbidden oxygen lines and intensities of these lines relative to those of the other emissions. This would be useful for the study of the excitation mechanism responsible for the emission of these cometary [O I] lines as well as for the determination of abundances in cometary atmospheres.

The writer believes that an amplification of the compiled cometary spectral and other cometary characteristics, so well begun by L. Remy-Battiau and P. Swings (1966), would greatly advance our understanding of the nature of comets.

D. Structure and origin of the nucleus

The writer is delighted with the increasing attention, both observational and theoretical, being given to physical studies of cometary nuclei. A. H. Delsemme (1966*a*, 1966*b*) has made the most comprehensive effort to date in developing a specific icy model. He explores the vital role of hydrates in the chemistry of the parent molecules, and limits his basic model to H_2O, CH_4, NH_3 and earthy dust. He calculates rather successfully the surface conditions at various solar distances to predict the onset of activity for an incoming comet. Much depends upon the abundances, particularly whether there is an excess of CH_4. He suggests that the albedos may be appreciably higher than for the Moon.

W. F. Hübner (1965*a*, 1965*b*, 1966) and with A. Weigert (1966) have laid particular stress on the role of ice grains in the immediate neighborhood of the nucleus as producing opacity to reduce solar radiation and to induce observable effects near the nucleus. They develop a theory for the rate of gas production in comets, for brightness outbursts of P/Schwassmann-Wachmann I at great solar distances, and for the strength of [O I]. Dobrovol'skij (1966) also demonstrates the great possible opacity of dust to solar heating of the nucleus. He also (1964*a*, 1964*b*) discusses the action of solar corpuscular radiation on ices of the nucleus and a possible mechanism for solar-flare reactions involving free-radical formation on the nucleus. V. Vanýsek (1966) discusses the nature of cometary dust and its marked variation in observability; e.g., Comets Arend-Roland (1957 III) and Mrkos (1957 V) show 100 times the dust/gas ratio of P/Encke and others.

B. J. Levin (1966) raises the important problem of the transfer of volatiles from beneath the surface to adsorption on the meteoritic surface, particularly for periodic comets. He concludes that the fall in absolute magnitude ($\sim 1^m$) repeatedly noted for Comet P/Encke shortly after perihelion is caused by the nearly complete desorption of gases from the surface and exhaustion of available volatiles just below. He stresses that this phenomenon occurs frequently in comets. In 1964 V. Vanýsek (1965) noted that for P/Encke this brightness loss was extraordinary ($\sim 4^m$) and suggested that it arose from a complete cessation of nuclear activity due to complete exhaustion of the active layer, the rate of luminosity loss being about that expected for molecules of lifetimes some 10^5 s. The writer here points out a possible alternative, viz., that periodic comet nuclei are active at any time only in a finite number of areas, and that momentarily all were inactive for Comet Encke. Observed jets from nuclei tend possibly to support this alternative. The answer to this problem is important.

W. Liller (1966) finds that desorption energies calculated by the Levin formula appear to apply well for Comet Arend-Roland (1957 III). J. Remy-Battiau (1964) concludes that cometary bursts are not due to solar particles but arise from some phenomenon in the nuclei, possibly involving dust.

E. Roemer (1966*a*, 1966*b*) made a significant advance in our knowledge of the dimensions of cometary nuclei by measuring limiting magnitudes for 18 periodic and 11 nearly parabolic comets. Depending on the comet and the assumed albedo, the radii lie in the range 0·1 to 65 km.

From P. E. Zadunaisky's (1966) definitive orbits of Halley's comet (1910 II) before and after perihelion, Z. Sekanina (1967*a*), using his general theory (1967*b*), shows that the orbital changes could have arisen by selective loss of 0·5% of the mass of the nucleus. He discusses in detail the splitting of Comet Ikeya-Seki (1965*f*) (1966*a*). B. Marsden (1966) is investigating the orbits of the sun-grazing comets and finds tentatively no evidence for physical accelerations.

From a study of 13 split comets, R. B. Stefanik (1966) shows that splitting of cometary nuclei without apparent physical cause is frequent among 'new' comets in any observable part of their orbits. Velocities of separation are of the order of 10–30 m s^{-1}. He and the writer (Whipple and Stefanik 1966) investigated the possibility that icy nuclei were originally heated by radioactivity to drive the most volatile materials out to the surface layers where they froze. Splitting could then result by heat shock when they first approach the Sun.

B. Donn (1964, 1965) discusses the growth of icy comet nuclei in space and the physics of compaction under gravity. N. Richter (1966) summarizes the general problems related to the origin of comets. D. McNally (1966) compares various common problems of the interstellar medium and the origin of comets.

In a series of important articles, E. J. Öpik (1966*a*, 1966*b*, 1966*c*) develops in more detail the orbital consequences of comets crossing the orbits of planets and his estimate (1966*a*) of 10^4 to 10^5 old nuclei trapped within the orbit of Jupiter. He shows that lunar ejecta cannot account for the meteorites and concludes that they come from the old comets (1966*b*). He expands theories of cometary accretion (1966*c*) within a Laplace-type nebula and almost disproves the possibility of the gravitational lens as a formative mechanism. He shows that accretion of comets in the present Oort cloud is impossible and shows how planetary perturbations could disperse comets from the planetary plane to this diffuse cloud. There is much food for thought, calculation and observation in Öpik's writings. The question of cometary and/or asteroidal contributions to the Apollo group of Earth-crossing bodies is vital to resolve.

The most recent general qualitative summary of theories of the origin and formation of comets is that by P. Lancaster-Brown (1964). The writer believes, however, that his hope for comet regeneration by any accretion process within or near the solar distance of the planets must be abandoned in view of the space measures of the solar wind. All isolated small bodies (possibly including the Moon) appear to be dissipating their mass.

J. L. Greenstein (1966) finds that possible nuclear processes appear at present to be unobservable in comets and hence of little current interest.

A number of contributions on the motions of comets and their source but not directly related to their physics are of interest to this Commission. They are presented by reference only, but starred (*) with slightly longer than usual abstracts (Arnold 1965, Brady 1965, Dufay in press, Harwit 1966*a*, 1966*b*, Krésak 1965, 1966, Lyttleton and Hammersley 1964, Makover 1964, Piotrowski 1965, Sekanina 1966*b*, 1966*c*, 1966*d*, Sitarski 1964, Šteins 1964, Šteins and Kronkalne 1964*a*, 1964*b*, Vsehsvjatskij 1965, 1966*a*, 1966*b*, 1966*c*). It is encouraging to see so much attention given to these basic problems of cometary orbits and perturbations.

E. Coma, excitation and ionization

K. Wurm (1966*a*, 1966*b*) with A. Mammano (in preparation) and with J. Rahe (in preparation) and the latter (Rahe 1965) for various comets, particularly Comet Donati, 1858 VI, find major excitation and ionization within 500 km of the nucleus with time scales of only 100 s. See also Öpik (D 1966*a*, D 1966*b*, D 1966*c*). Nearly symmetrical streaming occurs for neutral particles; for CN it is 1/2 km s^{-1} corresponding to $T \sim 500°K$! Expulsion to $\sim 150\,000$ km requires the turning of ions to the tail axis. These processes show no clear dependence on solar distance. The ions stream only towards Sun, so that type-I tails originate in the nuclear region. Wurm and his collaborators still find no explanation for such rapid and extensive excitation, ionization and motions in conventional processes, including the solar wind, and suggest intrinsic processes such possibly as effects of electrical fields.

In an important contribution on the mechanism of ionization and excitation in comet heads, L. Biermann and E. Trefftz (1964) find that the excitation of [O I] lines must predominantly take place in photodissociation to produce the atom from parent molecules. They require copious production of parent molecules from the nucleus, more than is apparently required to account for the C_2, CN and CO$^+$ bands. In bright comets they find as do others that gas densities must be high enough to permit exothermic chemical reactions up to distance of 10^4 km or more; in this way they form CO$^+$. They find a long time scale (> 10 d) for some primary ionization. They extrapolate their theory to the ultraviolet, predicting radiation flux, and discuss detailed processes of ionic dissociation of several parent molecules such as H_2O^+, H_2^+, C_2H_2, CO_2, and C_3H_4. V. Čeredničenko (1965, 1966), for a comet at $r = 1$ A.U. analyzes all possible transformation processes for C_2N_2, $C_2N_2^+$, CN, CN$^+$, N_2, N_2^+, C_3H_6, $C_3H_6^+$, C_2H_2, $C_2H_2^+$, C_3, C_2, CH_2, CH_2^+, CH, H_2, H_2O, H_2O^+, OH and OH$^+$ in the field of solar photon and corpuscular radiation (using old data on solar radiation). W. M. Jackson and B. Donn (1966*a*) carried out Monte-Carlo calculations on molecular collisions near a comet nucleus and discuss possible parent molecules for C_3. They calculate (1966*b*) the photochemical yield near the nucleus for parent molecules. They expect CO^+ near the nucleus.

J. Bouska (1965*a*, 1965*b*, 1966) and E. B. Kostyakova (1965) determine the intensity distribution in the head for Comet Arend-Roland (1957 III). Ju. N. Gnedin and A. Z. Dolginov (1966*a*, 1966*b*) and D. O. Mokhnach (1966*a*, 1966*b*) derive theoretical formulae for the distribution of parent and luminous molecules (mostly C_2 and CN near the nucleus) and compare them with photometric observations. They calculate numbers of molecules produced and lost, lifetimes, velocities and general distribution of molecules in the coma. Much of this work follows L. Haser's model discussed by this Commission in 1964. He has continued and expanded his 'fountain model' in the meantime (1966).

F. D. Miller (1965*a*, 1965*b*) discusses the forms of the coma and velocities for particles and gas, showing how a bright leading edge may be produced by a suitable repulsive force (Comets Mrkos, 1957 V, and Seki-Lines, 1962 III). V. Rijves (1960*a*, 1960*b*, 1963) develops the problem of the high rate of expansion of gases and the deviation of ions into the tail from the heads of comets while N. G. Ptitsina calculates the geometry of cometary envelopes on the basis of hydrodynamical processes. J. Dufay (in press) involves molecular excitation by electrons in the outer corona for sun-grazing comets. For Comet Mrkos (1957 III) M. F. A'Hearn (1964) analyzes C_2 densities.

For the intensity ratios of the [O I] lines in a comet, N. S. Kovar and R. P. Kovar (1966) develop a theory in terms of the electron density and temperature within the coma. They too require molecular processes. They determine (B 1965*a*, B 1965*b*) the ratios of C_3/CN and CH/CN in Comet Ikeya, 1964*f*.

V. Vanýsek (1965) finds that systematic changes in observed color indices for several comets depend upon the diameter of the photoelectric photometer used and ascribes the effect to different lifetimes of CN and C_2 molecules coupled with effects due to ice grains ejected from the nucleus. A similar study by M. E. Dewey and F. D. Miller (1966) for Comet Seki, 1961 VIII, from isophotes gives valuable information on lifetimes of C_2 and its parent molecule.

For Comet Morehouse, 1908 III, W. Schlosser (1966) has measured 210 Greenwich plates to determine motions in and about the head. He finds a velocity expansion of 2·4 km s^{-1} coming to zero within about a day after an outburst. He has many measures on condensations and development of tail rays, including sinusoidal motion. Studies of forms and motions in the heads of comets have been carried out by O. V. Dobrovol'skij (1966) for Comet Honda, 1955 V, and P. Egibekov (1964) for Comet Ikeya, 1963*a*. Dobrovol'skij utilizes observed solar UV radiation (300–1700 Å) and finds that the lifetimes of CO and CO_2 molecules before ionization are too long ($\sim 10^6$ s) for them to produce CO^+ and CO_2^+ by solar photoionization.

J. Rahe (1966) not only finds parabolic structures about the nucleus but points out again certain extraordinary curved arcs radiating from the nucleus of Comets 1861 II, 1862 III and Halley. Special observations suppressing CN at λ 3883 would expedite observations of complicated head features.

The contributions of this section generally avoid magnetohydrodynamic processes of ionization, dissociation or excitation by solar wind. Among many overlapping papers discussed in other sections of this Report, those by Bouska and Mayer (B 1966), Hübner (D 1965*a*, D 1965*b*, D 1966), Hübner and Weigert (D 1966), Ioffe (F 1965, F 1966*a*, F 1966*b*), Nazarchuk (B 1965), Malaise (B 1966) and Vanýsek (D 1966) should perhaps be mentioned. Much of the theoretical material of this section received thorough treatment in the 1964 Report of this Commission. Since that Report we find considerable progress in measures and in the treatment of molecular lifetimes. A great spurt of progress should occur when radiations from the parent molecules can be observed directly from space stations. We still observe too few of the many processes occurring in the heads of comets for a truly satisfactory understanding of them.

F. Type-I tails

Opinion is still divided as to possible correlations between cometary plasma tails and general solar activity. D. Antrack, L. Biermann and Rh. Lüst (1964) in an extensive statistical treatment find no such correlation and a probably smaller decrease with heliocentric latitude than Stumpff had found. But for Comet Tomita-Gerber-Honda (1964 VI) they (Biermann and Lüst 1966) and M. F. A'Hearn (1965) suggest strongly that a tail knot and curvature were related to the solar event of 4 July 1964. R. Pflug (1966) from the orientation of 323 observations of 11 comet tails found no correlations with the phase of sunspot activity or the heliocentric distance. The scatter in direction, however, was greater at sunspot maximum. He suggests that more active regions (not flares) produce lower solar-wind velocity and greater comet brightness.

Regardless of uncertainties in detailed relations between solar activity and type-I tails, few investigators question that the solar wind controls the motions of the ionic tails. The analogy with the Earth's magnetosphere (e.g., Ness 1966) is compelling. The massive effort by J. C. Brandt and M. J. S. Belton (A 1966) in measuring carefully the orientation of 1607 plasma tails, in addition to the work of Pflug (1966), has led (Brandt 1966*a*, 1966*b*, and 1966*c* with M. J. S. Belton and M. W. Stephens 1966) to striking conclusions. The measures confirm the assumption that statistically a plasma tail is directed nearly in the plane of the orbit in a direction measured by the combined velocity vectors of the solar wind and cometary motion, the aberration angle. There is a sharp velocity minimum to the solar wind of some $150 \pm 50\,\mathrm{km\,s^{-1}}$ (Brandt 1966*c*, Brandt *et al.* 1966) and a mean velocity of $500\,\mathrm{km\,s^{-1}}$ with only a $50\,\mathrm{km\,s^{-1}}$ probable spread in means between solar maxima and minima. These values agree broadly with the directly measured velocities from space probes by, e.g., C. W. Snyder, C. W. Neugebauer and U. R. Rao (1963) and N. F. Ness and J. M. Wilcox (1964).

Brandt (1966*c*) finds that the comet tails, Mariner II and storm data are consistent with the following expressions for the solar-wind velocity:

$$w = 330 + 9\ \Sigma K_{\mathrm{p}} \qquad (\mathrm{km\,s^{-1}})$$

or

$$w = 316\ A_{\mathrm{p}}^{0\cdot 20} \qquad (\mathrm{km\,s^{-1}}),$$

where ΣK_{p} is the sum of the geomagnetic index K_{p} for the day in question and A_{p} is the surface magnetic-disturbance index. A residual tangential component (Brandt 1966*a*, 1966*b*, 1966*c*, Brandt *et al.* 1966) of about $10\,\mathrm{km\,s^{-1}}$ in the effective solar wind is directed forward in the sense of the solar rotation. Brandt (1966*c*) doubts that a latitude dependence of the plasma velocity can be determined at present and suggests that Pflug's (1966) results of a minimum velocity at the latitude of the sunspot zone may be due to the non-uniform distribution of cometary data.

G. Guigay (1966*a*) confirms similarly a wind velocity of some $400\,\mathrm{km\,s^{-1}}$ for the tail of Comet Ikeya-Seki (1965*f*) but notes (1966*b*) that for distant Comet Humason (1961*e*) the tail is sometimes well in advance of the radius vector to the Sun as does E. J. Öpik (1956, 1964) in his report on motions in the tail of Halley's comet. Similarly, K. Wurm and A. Mammano (1964) find that for Comets 1908 III and 1911 V the tails varied irregularly in direction while for 1907 IV the tail axis lay in the plane of the orbit. They find, however, a systematic lag (25°).

The theory of type-I tails has developed conceptually from solar light pressure (inadequate), through L. Biermann's (1951) direct interaction of solar and cometary ions (wind flux inadequate) to H. Alfvén's (1957) magnetohydrodynamic (MHD) coupling. He visualized the supersonic collisionless MHD shock wave developing about the ions in a comet head, with dimensions comparable to the observed head. Our knowledge of the solar wind and the ultraviolet solar radiation have become precise through the measures made from space vehicles (e.g. Gringauz *et al.* 1960, Synder *et al.* 1963 and Ness and Wilcox 1964) while improved physical theory has shown that solar radiation is inadequate to produce the cometary ions copiously enough to fit the improved observational data of comets. We now know that the type-I tails are essentially ionic and that the solar wind carries enough momentum to carry along the observed ion clouds if the MHD net can selectively couple with the cometary ions independently of the neutral molecules over the large areas involved. The next step by M. Harwit and F. Hoyle (1962*a*, 1962*b*) attempted to solve these problems by charge exchange from the protons. Theoreticians now appear to agree that electrons not protons must and can produce this ionization, and that electrons also play a major role in the MHD coupling, chiefly because of their enormous mobility compared to protons or heavier ions. Other problems concern the complex ray structures and their motions.

An excellent qualitative view of plasma theory can be obtained from the discussions of L. Biermann (1966) and N. F. Ness and B. D. Donn (1966). The latter (and Ptitsina, below) show how the complexity of the ray structure is qualitatively explained by the MHD neutral tubes and sheaths as pointed out by W. I. Axford, H. E. Petschek and G. L. Sicoe (1965) while the enormous role of electrons, including their ability to excite [O I] lines, was stressed by Axford (1964). Major contributions to this theory have been made by L. Maročnik (1963, 1964) in studying the disturbed shock region for both pressure and ionization effects; N. N. Kazantseva (1966) who considers an oblique collision between the corpuscular stream and the cometary plasma and N. G. Ptitsina (1964, 1965) who develops an MHD approach to the study of moving envelopes and ray structures in plasma tails, comparing them with observations of Comet Morehouse, 1908 II; Z. M. Ioffe (1965, 1966*a*, 1966*b*), who calculated the shape of the coma and plasma tails from a theory of supersonic plasma flux about a cometary head for a three-dimensional compressible medium; D. B. Beard (1966), who stressed the rolę of electrons and charge separation in tail structure formation; L. Biermann, B. Brosowski and H. U. Schmidt (1966), who developed in detail the shock front or 'contact' surface concept some 10^6 km ahead of the cometary head; and N. S. Kovar and J. W. Kern (1966) who have developed an MHD model for comets.

A most detailed theory has been developed by M. K. Wallis (1967) showing how transverse plasma instabilities couple the motions of the solar wind to the comet plasma. He finds viscous heating important in maintaining the ray structures some 100 times their widths against diffusion *without* a magnetic field. This theory shows promise of clearing up some of the major problems of tail ray structure, while almost all of the theories, in analogy with the Earth's magnetosphere, show how extended tail streamers can converge back on the major axis of flow as so frequently observed. Great progress is being made!

Other theoretical papers concerning the interaction of photons, corpuscular radiation and molecules magnetic-field induced in comet heads are by V. I. Čeredničenko (1965*a*, 1965*b*, 1965*c*), L. S. Maročnik (1963, 1964) V. M. Južakov (1963). Other observational and theoretical papers besides Belton and Brandt (A 1966), Nazarchuk (B 1965) include E. Fajziev (1964), solar distance effects; Z. Sekanina (1966), diameters of coma of many comets and action of solar wind; Bernasconi (1965), method for calculation of true cone of cometary tail; J. Bouska (1964), velocities and acceleration in the tail of Comet Arend-Roland 1957 III and Nazarchuk (B 1965), on the theory of corpuscular radiation on the tail of the same comet; O. V. Dobrovol'skij (1964*a*, 1964*b*), accounting for cometary bursts by sudden increases in the solar wind; E. Öpik (1965), on theoretical failure of solar radiation or exchange mechanisms with the solar wind to explain the abundance of CO^+ ions in type-I tails; C. E. Kearns and K. Rudnicki (1965), velocities in tail of Comet Humason 1962 VIII; Ch. Cailliatte (1966), method for determining the true divergence of gas and dust tails; and Rh. Lüst (in press), streaming of CO^+ features fairly parallel to tail axis of Comet Morehouse 1908 III, but *no* evidence that CO^+ formed close to the nucleus.

G. Type-II and -III tails

Ejection, motions and properties of dust in comet tails were studied by a few investigators: O. Dobrovol'skij (in preparation), from an analysis of all published data on simultaneous determinations of ejection velocities and accelerations of dust particles, found a uniform numerical relationship in the head and tails of comets; for Comet Arend-Roland (1957 III) E. Fajziev (1964*a*, 1964*b*) determined graphically the initial velocity of particles ejected into the tail; M. L. Finson and R. F. Probstein (1966) studied the motions of dust carried out of a cometary nucleus by the expanding gas and pressed backward by light pressure.

With the exception of Finson and Probstein, most investigators are dissatisfied with the application of the Bessel-Bredikhin mechanical theory to type-II comet tails, particularly to the formation of synchronic bands, e.g., A. A. Demenko (1966) from a study of three photographs of Comet Seki-Lines, 1962 III. He further develops the theory for analysis of these bands. B. J. Levin (1964, 1966), M. J. S. Belton (1965, 1966) and P. Notni (1964, 1966) agree that the classical theory is not satisfactory and that the evidence points almost conclusively to forces arising from the solar wind. They do not, however, agree on the detailed physical mechanism at work.

Levin (1964) notes that Na is highly accelerated in the tail of some comets but that the lifetime of the neutral atom is too short. He argues (1966) for the recognition of Bredikhin's type-III tails and suggests strongly that molecules are also present and active in the so-called dust tails. Belton (1965, 1966) shows that type-II tails lie in the orbital plane but are directed away from the Sun much forward ($h \sim 1$) to the direction expected on the basis of light pressure alone. For ten comets the effects are similar and independent of solar distance. A postulated interplanetary drag is unsatisfactory. Ejection velocities to explain synchronic bands are too high for dust. He suggests that electrons may interact with the dust and solar plasma. Notni (1964, 1966) independently notes the theoretical difficulties of the classical theory and suggests that dust particles in a plasma may encounter high electron density (10^7–10^8/cm^3) and attain surprisingly high negative charges (up to $-$ 100 eV) so that the MHD plasma can interact to produce strong repulsive forces radially from the Sun. CO^+ ions may interact.

Thus it appears that some uncertainties still remain in dust-tail theory. Also there remain serious theoretical doubts as to the major processes for dissociation and ionization and even observational questions as to the location and time scales of these processes.

H. Laboratory work

In addition to the monographic papers on cometary spectra already mentioned, by P. Swings (A 1965) and C. Arpigny (A 1965), we point out J. G. Phillips' (1966) valuable summary of related laboratory spectroscopy, including a bibliography of recent spectroscopic data and physical properties of a number of possible parent molecules in comets. From laboratory studies he presents dissociation energies and ionization potentials for C_2, CH, CH^+, CN, CN^+, CO, CO^+, NH, NH^+, N_2, N_2^+, OH, OH^+, and oscillator strengths for certain systems of CO, CO^+, CO_2^+, and N_2^+. He found that he could derive OH emission by bombarding methanol (CH_3OH) so that H_2O is not necessarily the parent molecule. L. J. Stief and V. J. DeCarlo (1965) can obtain C_2 bands by dissociating CH_4 and C_2H_2 but not from C_2H_4 and C_2H_6. W. M. Vaidya (1966) compares spectra of comets and hydrocarbon flames to find certain cometary bands of CH and OH in a Bunsen flame. In an ethylene flame he finds a new spectrum, of HCO; possibly in comets?

In the Spectroscopic Laboratory of the National Research Council of Canada the study of the spectra and structures of diatomic molecules and simple polyatomic molecules and free radicals has been continued. Recently G. Herzberg (1966) has found a new simple band system that represents a Σ_u^+–Σ_g^+ transition of either C_2 or C_2^+ or C_2^-. The 0–0 band of this system is at 5416 Å. It would be clearly of interest to see whether this spectrum occurs in comets.

Several studies of diatomic hydrides have been carried out during the last three years. The work by Herzberg and Johns on CH, mentioned in the earlier report, has not yet been published, but the value of the ionization potential (10·64 eV) given earlier must be considered as reliable. Clear evidence of predissociation in the $B^2\Sigma^-$ state has been obtained in absorption. Furthermore, it was established that in fluorescence the $C^2\Sigma^+$–$K^2\Pi$ transition of CH does not occur or is very weak, while the corresponding transition in CD is strong. This observation suggests very strongly that the $C^2\Sigma^+$ state is subject to strong predissociation in CH but much less in CD. Two new absorption systems of SiH (and SiD) have been found and analyzed by Verma (1965). Both upper states are $^2\Sigma^+$. The first system is at 3250 Å and might be of interest for cometary spectra. In addition, considerable work has been done on the spectra of BH (Bauer *et al.* 1964) and SH (Morrow in press). Most of these spectra are in the vacuum ultraviolet.

New and very interesting spectra have been found of NF by Douglas and Johns (in press) and Johns, and NCl (Colin and Johns in preparation). These spectra are analogues of the atmospheric oxygen bands. A brief investigation of the spectrum of CCl has shown that the excited $A^2\Delta$ state is a regular state.

In an unpublished investigation by Herzberg, the spectra of N_2^+, CO^+, and CO_2^+ have been observed for the first time in absorption.

With regard to triatomic molecules, the following spectra may be of interest. The investigation of the red band of CH_2 found several years ago has now been completed and is about to appear (Herzberg and Johns in press). The red bands correspond to the singlet form of CH_2. A similar spectrum of BH_2 involving the ground state of this free radical and occurring in the red and near infrared regions has been observed and studied by Herzberg and Johns (in press).

An extensive study of the 4050 Å group of the C_3 radical on the basis of absorption spectra obtained in the laboratory has been published by Gausset *et al.* (1965, 1966). This spectrum is now rather well understood. The paper mentioned contains also a spectrogram of the fluorescence of the flash photolysis of diazomethane which shows a striking resemblance to a cometary spectrum since it contains not only very strongly the spectrum of C_3, but also those of C_2 and CN.

Other triatomic molecules recently studied at Ottawa and of possible interest to cometary physics are: CCN (Merer and Travis 1965), CNC (Merer and Travis 1966), NCN (Herzberg and Travis 1964), N_3 (Douglas and Jones 1965) and CO_2^+ (Johns 1964). All these spectra are quite extensive with characteristic bands that should be readily identifiable in cometary spectra if they occur. E. Stokes Fishburne and K. N. Rao (1966) show reproductions of high-dispersion spectra of CO^+, 0·2 Å/mm.

Other related spectroscopic work: Ch. Jungen and E. Miescher (1966) on emission NO in the UV; H. Papazian (1966), an unknown absorption band, 210–230 mμ, from photolysis of solid HN_3 and, in progress, a study of radicals from photochemical reactions; A Monfils (1965*a*, 1965*b*) on absorption spectra of H_2, HD and D_2; W. Jackson, S. Glicker and B. Donn, in progress, photochemistry of benzene and other aromatic compounds as potential cometary parent molecules.

Laboratory studies of the bombardment of cometary molecules by ions and electrons are of particular importance in interpreting cometary spectra in terms of physical processes.

M. Dufay, Marie-Claude Poulizac (1966) and with J. Desesquelles (Poulizac *et al.* in press) have studied the spectra at λλ 2500–8900 Å of CO and CO_2 excited by H^+ and H_2^+ at 30–600 keV and pressures of 10^{-5} to 10^{-1} mm Hg. They find interesting line and band structures for C I, C II, O I, O II, CO^+, CO and CO_2^+. The vibration levels correspond to high temperatures. Measurements are made of cross sections for ionization and charge exchange for H^+ ions.

Other molecules currently under study in this fashion are CH_4, C_2H_4, C_2H_6, C_2H_2 and CH_4. A. G. Koval', V. T. Koppe and Ja. M. Fogel' (1966*a*, 1966*b*) have studied the emission spectra of N_2^+, CO^+, CO_2, CO_2^+ and others excited by 13 keV electrons.

R. Herman (1966) is conducting an interesting experiment in the polymerization and growth of carbon particles from hydrocarbon molecules in an electrical discharge. Results are somewhat like those from photolysis. She finds growth, C_2, C_3, etc. and also direct catalytic dissociation of hydrocarbon molecules on the carbon surface.

I. *Space experiments*

P. T. Gronstal and R. P. Bukata (1966) looked for 0·1 to 1·0 MeV protons from Comet Ikeya-Seki (1965*f*) by balloon-supported equipment on 20 October 1965. No cometary effects could be detected.

H. Föppl *et al.* (1965, 1967) and G. Haerendel *et al.* (in press) have carried out seven artificial plasma experiments as proposed in 1961. Reacting compounds, $Ba(NO_3)_2 + 4\,Al$ or $4\,La$, $Sr(NO_3)_2 + 6\,Mg$ or $Ba(NO_3)_2$ or $3\,BaO_2 + nAl$ or nMg were sent by rocket as high as 2000 km. Approximately 100 g of Ba II could be observed at such heights, even when distributed over 10^5 km². The diameter of the clouds increased faster than by purely molecular diffusion. Wind shears could be measured. Ionization of 5 to 7% could be reached. The cloud of neutral Sr was observed over the range of optically thick to thin. The time constant for removal of the radiating material by the atmosphere was $\sim 10^3$ s. The ionized clouds tended to diffuse along the lines of the geomagnetic field. Attempts will be made to reach heights $> 10^5$ km.

H. Bredohl (1966) reports on Professor Rosen's equipment that released liquid ammonia at an altitude of 200 km from an ESRO rocket, July 1964. Various spectrophotometric and photometric instruments detected feeble emission of NH_2, and measured the expansion and polarization of the cloud. The experiment is encouraging for future such research and points up certain needed ground-based experiments and observations.

A. Potter (1966) has produced a cloud of CN radicals at 150 km in a rocket experiment and has investigated the origin of free radicals in comet heads.

Although E. J. Öpik (1965) has shown sound reasons for doubting the observability and therefore the value of artificial comet experiments in deep space, especially those involving icy masses, the liquid experiments in the high atmosphere have proved to be of great interest and value. As he points out, however, many ground-based experiments are sorely needed to clarify actual physical processes in comets, regarding both observed phenomena and mode of formation.

In planning for possible space missions, 'fly-bys' at 10^3 to 10^4 km from a cometary nucleus, R. L. Roberts, F. Narin and P. M. Pierce (1966) have calculated missions for 110 periodic comets during the interval to Halley's in 1986. They discuss possible scientific objectives, instrumentation and specifications. About one such mission a year is theoretically possible. See also P. Swings (A 1965).

II. ADMINISTRATIVE REPORT

It is very encouraging to note the degree to which past recommendations to Commission 15 have been applied by observers. Narrow-band and monochromatic photometry have been used effectively for several comets. A broad use of the photographic archives of comets has been a source of very real contribution during the past years. A number of observatories have been most generous in allowing visiting astronomers to utilize their photographic collections.

Professor Wurm's distribution of copies of cometary photographs has been a start toward a wider distribution of this sort. More discussion is needed concerning the bringing together of the proposed Atlas of Characteristic Cometary Forms.

In spite of the existence of astronomical observatories over most of the globe they are still far from successful in even the simple photography of cometary forms on a continuous 24-hour basis. Also we are still far from such a continuous photoelectric photometric program as was suggested by Dr Vsehsvjatskij. These matters should receive more consideration to ascertain whether important bright comets cannot be followed more completely than in the past.

It is not clear whether further Commission recommendations are essential to the production and study of 'artificial comets' by various national or international space programs. Further discussion of this matter appears to be needed, perhaps in consultation with representatives of Commission 44.

F. L. WHIPPLE
President of the Commission

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