

SPECTRA OF COMETS

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All cometary spectra are characterized, in wave lengths longer than 3800 Å, by the emission bands of *CN*, *CH*, and *C₂*, and by some unidentified features, the most conspicuous of which are near λ 4050. At small heliocentric distances, the D-lines of *Na* also appear. In the ultraviolet region, strong bands are observed, due to *OH*, *NH*, and *CN*,¹ plus certain very faint unidentified features. Except for the Swan bands of *C₂*, which have an appearance similar to that obtained in the laboratory, all the bands have a peculiar distribution of intensity. Besides the molecular bands, cometary spectra also reveal a solar spectrum, which results from the reflection or scattering of solar light by the meteorites forming the cometary nucleus. The relative intensities of the reflected solar spectrum and of the molecular bands vary from comet to comet,² even for the same heliocentric distance. Not only do the amount and density of the gas surrounding the nucleus vary from comet to comet, but even the chemical composition of the gas varies from one comet to another. Although definite conclusions as to the chemical constitution of cometary atmospheres are still premature, it appears that when the solar spectrum is weak compared with that of *CN*,

¹ One may wonder how a "low-temperature source," like a cometary atmosphere, can contain radicals such as *OH*, *CH*, *CN*, *NH*, *C₂*, that are not chemically stable. Actually these compounds are physically stable, since their ground electronic state has an energy that is smaller than the energy of the separated atoms. Molecules are considered as chemically stable if they can exist for an appreciable length of time even when colliding with each other at low temperatures. *OH*, *CH*, *CN*, etc., are thus not chemically stable, but they may be present in cometary atmospheres because of the low densities prevailing in such atmospheres, and the consequent almost complete absence of collisions. Similarly, *CH*, *CN*, and *CH⁺* are observed in another "low temperature gas" of very low density—the interstellar gas.

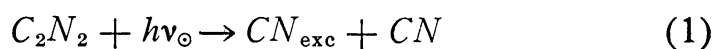
² The relative intensities of bands due to different molecules also vary with heliocentric distance, but additional observational data of more quantitative character are required for the discussion of the physico-chemical mechanisms involved.

the bands of CN , C_2 , and CH are all strong. When the solar spectrum is strong, CN is much more conspicuous than the other molecules containing carbon (C_2 and CH). The bands of the two molecules that do not contain carbon (OH and NH), behave differently: they may be fairly strong even when the solar spectrum is prominent. These variations in the chemical composition of comets are probably related to the chemical structure of the meteorites constituting the nuclei.

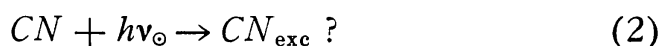
The physico-chemical interpretation of cometary spectra is complicated. The molecules giving rise to the observed bands cannot exist as such in the occluded state in the meteoritic solids, since they are not chemically stable. They result from the photodissociation of more complex, chemically stable, parent molecules which were present in the solid nuclear particles as occluded gases. What the parent molecules are is still unknown. We do know, however, that there are different chemical types of meteorites containing a variety of occluded gases and it is logical to assume that the cometary radicals result from the photodissociation of the meteoritic gases by solar radiation.

THE EXCITATION MECHANISM

For the general problem of the chemical constitution of comets, it is important to ascertain which excitation mechanism gives rise to the emission of molecular bands. It has usually been assumed that the bands, and also the Na lines, are emitted in a fluorescence process excited by solar radiation. Good theoretical reasons, related to the total brightness of comets, or to the total sodium emission, have been given for this assumption. Polarization effects observed by Y. Öhman also point definitely in the same direction. Before accepting this assumption we may wish to make more direct spectroscopic tests. We may question whether the molecules are not brought into the excited state as a result of the photodissociation process. For example, does the CN -emission result from a dissociation such as



or simply from a pure resonance excitation



There is a possibility of deciding between these two mechanisms on the basis of the intensity distribution among the rotational lines of CN . This distribution is actually quite complex. All the cometary bands of CN , CH , OH , and NH have rotational intensity distributions which correspond in general, but not exactly, to a low temperature of the order of 300° K. By this, I mean that only the lines arising from the first rotational levels are observed ($K' \leq 3$ for OH ; ≤ 2 for NH ; ≤ 6 for CH ; ≤ 20 for CN). The intensity distributions among these lines of low rotational quantum number, however, does not closely resemble any smooth distribution similar to one of the Boltzmann type. For example, in the (0,0) transition of CN , the P branch has a first maximum around $K' = 2$ or 3, a deep minimum around $K' = 5$ or 6, usually a second weak maximum for $K' = 8$, a second weak minimum for $K' \approx 9$, sometimes followed by two maxima. A similar intensity distribution is observed in the R branch, and there is no doubt that the excited levels $K' = 2$ and 3 (always), 8, 11, and 15 (often) are favored as compared with the others. The rotational intensity distribution is not quite the same in all comets, but all manifest a number of favored rotational levels. It should be pointed out that, since collisional effects are unimportant in cometary atmospheres, the rotational and vibrational structures of the bands attributed to a specific molecule result primarily from the distribution in the rotational and vibrational levels of the excited state. The isotopes may also influence the structure, a point which will be considered later.

If we assume an excitation in comets resulting purely from one or several photodissociations, we must assume that the selective favoring of certain rotational levels is due to these photodissociations. The data available at present do not explain the observed CN structure, especially the variations from comet to comet and with heliocentric distance.

Let us now assume that the excitation of the CN -cometary molecules is due exclusively to the absorption of solar radiation. The population in an excited rotational level K' , from which the two emission lines $P(K' + 1)$ and $R(K' - 1)$ arise, can then be expressed by the following proportion

$$N'_{K'} \propto N''_{K'+1} \times p_P^{\text{abs}} \times I_P + N''_{K'-1} \times p_R^{\text{abs}} \times I_R, \quad (3)$$

where:

$N''_{K'-1}$ and $N''_{K'+1}$ are the populations in the rotational levels $K'' = K' - 1$ and $K'' = K' + 1$ of the ground electronic and vibrational state;

p_P^{abs} and p_R^{abs} , the transition probabilities of the absorption lines $P(K' + 1)$ and $R(K' - 1)$;

I_P and I_R , the intensities of solar radiation for the wave lengths of $P(K' + 1)$ and $R(K' - 1)$, corrected for the radial velocity of the sun with respect to the comet (ordinarily this correction is of the order of ± 0.25 A).

Whatever the distribution $N''_{K''}$ may be (in the simplest case, a continuous function of K'' with only one maximum), $N'_{K'}$ will depend on the spectral distribution of the solar radiation I . The important effect of the Fraunhofer lines appears strikingly when one plots the wave lengths of the P and R lines on a map of the solar spectrum. The deep minima in the solar spectrum in the region of P(6) and P(7), and between R(2) and R(7) are undoubtedly the cause of the very low intensity of the P and R lines corresponding to $3 < K' < 8$. Whatever the radial velocity may be, P(6) and P(7) will always fall in a deep minimum of the solar spectrum, caused mainly by $\lambda 3878.02$ (*Fe I*, lab. int. 400, \odot 8) and $\lambda 3878.57$ (*Fe I*, lab. int. 300, \odot 7). Also P(5) usually falls in a solar spectral region fainter than that near P(4). Another minimum in solar intensity occurs between P(9) and P(12). On the whole, it is possible to explain the observed structures in cometary spectra by assuming that the intensity maxima and minima result from solar excitation influenced by the Fraunhofer lines. The observed pattern should be considered as a superposition of "resonance doublets," each consisting of a P and an R line with intensities proportional to the quantity evaluated in (3). The result of the superposition may be quite different from the pattern obtained by an exciting radiation of constant intensity over the wave-length range considered. Precise photometric work will be required to determine from the observed pattern the rotational distribution in the ground electronic state. If this distribution is of the Boltzmann type, the corresponding "temperature" seems to be of the order of 300° K.

The effect of the radial velocity of the comet with respect to the sun should be pointed out. Whereas no probable radial velocity could prevent P(6) and P(7) from falling in a weak region, certain relative intensities may be very sensitive to a change in radial velocity which could bring the cometary absorption line inside or outside a strong Fraunhofer line. These considerations, when applied to various comets having different radial velocities with respect to the sun, but with similar heliocentric distances, have given an entirely satisfactory interpretation of the observed *CN*-structures. These same considerations may, of course, also be applied to one comet at different heliocentric distances.

Thus spectroscopic observation provides conclusive evidence in favor of a cometary *CN*-emission, entirely due to an optical absorption of solar light. Similar considerations when applied to the other molecules, *CH*, *NH*, and *OH* give a satisfactory qualitative explanation of band structures. The next important step should be a quantitative microphotometric investigation which would provide important data on the rotational distribution in the ground electronic state.

The procedure which we have followed, namely the decomposition of the exciting radiation into a number of "monochromatic excitations" should probably be used more generally in astrophysics. We are already acquainted with the monochromatic excitation of lines of *O III* and *N III* by the resonance transition of *He II* (and *O III*) in nebulae and in various bright-line stars (Bowen's fluorescence mechanism). The fluorescence mechanism also operates in a wide variety of objects and atoms. In every astronomical case of fluorescence excitation, the exciting radiation is quite different from black-body radiation: absorption lines, bands, or continua, or emission features are always present. The absorption or emission lines of the exciting radiation are shifted to a certain extent with respect to those of the excited gas because of relative velocities. Typical examples are the excitation in expanding or in stationary shells, in nebular or interstellar gases, and in the night sky. Quite similarly the ionization of atoms and molecules and the molecular dissociation depend essentially on the spectral distribution of the exciting radiations. Perhaps certain anomalies in late-type spectra may be caused in

part by extremely uneven distribution of light in the continuous spectra. The spectral regions concerned lie for the most part in the unobservable ultraviolet, and some hope may thus be raised that, by a comparative discussion of all these related problems, we shall eventually be able to determine the main characteristics of the far ultraviolet stellar spectra.

ISOTOPES

In 1930, N. T. Bobrovnikoff suggested that two faint bands observed at λ 4744 and λ 4751 in Comet Brooks and Comet Halley might be due to $C^{12}C^{13}$ and $C^{13}C^{13}$. The (1,0) band at λ 4744 would be the isotopic transition most easily detected in cometary spectra. My observations confirm the presence of C^{13} . Not only does the (1,0) band of $C^{12}C^{13}$ at λ 4745 appear, but also the (weaker) (2,1) transition at λ 4723, and the (very weak) (3,2) band at λ 4706. The three bands of $C^{12}C^{13}$ are described by Wright as hazy. Bobrovnikoff describes the (1,0) band at λ 4745 also as diffuse, whereas the $C^{12}C^{12}$ bands have sharp edges. It would not be surprising to find different rotational intensity distributions for the $C^{12}C^{12}$ and $C^{12}C^{13}$ bands in comets, corresponding to different distributions among the rotational levels of the ground electronic state.³ In $C^{12}C^{12}$, the rotation and the rotation-vibration spectra cannot be emitted as dipole radiations, because of the complete absence of dipole moment in the ground electronic level. The situation is different for the isotopic molecule $C^{12}C^{13}$ which may have an ordinary vibration-rotation spectrum since the properties of symmetry in the nuclei no longer exist. The corresponding electric dipole transition probability is undoubtedly small compared with CN or CH , for example, because the change of the dipole moment of $C^{12}C^{13}$ during the oscillations must be very small. Yet, as was indicated by Herzberg⁴ for HD and $N^{14}N^{15}$, the intensity of this weak dipole emission (or absorption) would still be considerably larger than that of the corresponding quadrupole emission (or absorption). Thus, whereas the highly excited rotational levels of the ground elec-

³ Similar considerations apply to the vibrational levels.

⁴ *Ap. J.*, **87**, 428, 1938.

tronic state of $C^{12}C^{12}$ can be "depopulated" only by quadrupole emission, a dipole mechanism of greater probability (although still intrinsically small) operates for $C^{12}C^{13}$. The $C^{12}C^{12}$ bands would be reduced to the first lines of the branches at very large heliocentric distances only, whereas the "depopulating" process would operate at smaller heliocentric distances for $C^{12}C^{13}$. The cometary wave lengths of $C^{12}C^{13}$ agree well with the wave lengths of the laboratory heads, indicating that the rotational intensity distributions of the $C^{12}C^{13}$ bands observed in Comet Brooks and Comet Halley do not differ from the laboratory distributions to the same extent as in the bands of CN .

No trace of $C^{13}N^{14}$ or of the compounds of deuterium could be detected in any cometary spectrum. Thus, except for bands of $C^{12}C^{13}$, the isotopes do not play an important role in the observed structures of cometary features.

RECENT IDENTIFICATIONS

Besides the spectra of the seven molecules that have been definitely identified in comets (OH , NH , CN , CH , C_2 , CO^+ and N_2^+), there still remained until recently a number of unidentified features.

Among these was a group of three lines at $\lambda\lambda$ 4231, 4238, and 4254, appearing in the wave-length range between the $\Delta v = -1$ sequence of CN and the strong CH lines. This group was measured in various comets, especially in Comet Brooks by Wright, in Comet Morehouse by Baldet, and in Comet Cunningham by the author. It deserves special attention because it extends, at least partly, into the tail. The lines of this group are due to the (0,0) band of CH^+ (system $^1\Pi \rightarrow ^1\Sigma$), and are respectively:

$$\begin{aligned} \lambda 4231: & \quad R(0) + R(1) ; \\ \lambda 4238.5: & \quad Q(1) + Q(2) ; \\ \lambda 4254.4: & \quad P(3) \end{aligned}$$

The (1,0) band of CH^+ also gives rise to three faint cometary lines at λ 3954 (R branch), λ 3963 (Q), and λ 3972 (P).

As is usual for the heteronuclear molecules with a permanent dipole, only the lines arising from low rotational levels

($K' = 1$ and 2) are observed; this "low-temperature distribution" is similar to that observed for CH , NH , OH , and CN . An examination of the intensity distribution in the exciting solar spectrum explains the observed rotational distribution quite well: for example, the absorption transitions to the level $K' = 3$, $v' = 0$, are more reduced by Fraunhofer lines than those corresponding to $K' = 2$, $v' = 0$, thus decreasing the intensities of the bright lines R(2), Q(3), P(4) relative to those of R(1), Q(2), and P(3) in the (0,0) band. The conclusion is that CH^+ molecules are present in the comet's head and in part of its tail.

Several very faint lines observed around $\lambda 3565$ were also unidentified. This region is complex because of the presence of a fairly strong sequence of CN ($\Delta v = +1$). Some lines are certainly not due to CN , and it appears very probable that they belong to the (0,0) band of OH^+ . Better resolving power than has been hitherto available is needed to make this tentative identification certain. The extreme complexity of the exciting solar spectrum in this region undoubtedly produces a very peculiar intensity distribution among the rotational lines of OH^+ .

By far the most puzzling unidentified feature is a group of strong lines near $\lambda 4050$. Elaborate discussions of this group have been published attributing it to C_2 (Deslandres-d'Azambuja system $^1\Pi \rightarrow ^1\Pi$), CN (tail bands), CH (1,1 band of the $^2\Sigma \rightarrow ^2\Pi$ system or a new system), NaH , etc. . . . The situation is still unsatisfactory, but the observational facts suggest an additional possibility. The observational facts are:

1. The $\lambda 4050$ group extends farther out into the comet's head than CH does.

2. On spectrograms showing NH and $\lambda 4050$ simultaneously, the extension of $\lambda 4050$ is similar to or slightly greater than that of NH .

3. With a dispersion of 55 A/mm, all the lines are fairly sharp, except $\lambda 4051.5$ (strongest line) and possibly $\lambda 4038.9$.

4. The lines to the violet of $\lambda 4051$ are stronger than those to the red.

5. The lines are not observed in any late-type star, which indicates that they are not due to a normal molecule consisting of two abundant atoms.

From these observations I suggest the following conclusions :

1. In order to produce sharp lines with a dispersion of 55 A/mm, the molecule giving rise to the λ 4050 group must be a hydride.

2. The hydride must be NH^+ , because all the other diatomic hydrides (neutral and singly ionized) of the light elements are accounted for. Moreover, since NH^+ is isoelectronic to CH , the strongest system of NH^+ might be expected to be similar to $A^2\Delta \rightarrow x^2\Pi$ of CH (λ 4300 band) and, in fact, the general appearance of the λ 4050 group is more or less similar to the cometary CH band near λ 4300.

3. If this identification is correct, the broader, strongest line at λ 4051.5 is a blend of the first lines of the Q-branch, and the R- and P-branches are respectively to the blue and to the red of λ 4051.

4. It is then logical to assign the observed lines as follows :

$$\begin{array}{ll} \lambda 4051.5: & \text{Q branch;} \\ \lambda 4043.4: & R_1 \\ \lambda 4041.9: & R_2 \end{array} \left. \vphantom{\begin{array}{l} \lambda 4051.5: \\ \lambda 4043.4: \\ \lambda 4041.9: \end{array}} \right\} K'' = 1; \\ \lambda 4038.9: & R_1 + R_2 (K'' = 2).$$

5. The approximate value of the rotational constant B_0'' is then 13 or 14 cm^{-1} . This value is not much smaller than $B_0'' (NH) = 15.30 \text{ cm}^{-1}$, and the increase in the moment of inertia (about 10 per cent) when passing from NH to NH^+ would be the same as that observed when passing from OH to OH^+ .

6. The general spectral location of the band is correct, although a comparison with other pairs of isoelectronic molecules indicates that the NH^+ spectrum would be a little more to the red (about λ 4400).⁵

An astronomical objection to these suggestions is the fact that no line of the λ 4050 group has been observed in interstellar absorption. If the strong λ 4050 group is due to NH^+ , we must assume that $f(NH^+)$ is large. Hence it would seem plausible to find the NH^+ associated with CH^+ in interstellar absorption. The final word is undoubtedly left to the laboratory spectroscopists, who, we may hope, will soon provide data on the un-

⁵ Private communication of Dr. G. Herzberg.

known NH^+ spectrum. It would also be very important to have spectroscopic data on CN^+ , C_2^+ , and the simplest polyatomic molecules which may be expected to be present with OH , NH , CN , CH , C_2 , CH^+ , CO^+ , and N_2^+ : polyatomic molecules consisting of three or more of the cosmically abundant atoms H , C , N , O .

DISTRIBUTION AND ABUNDANCE

Each type of molecule has a definite extension in the head, corresponding to the mean free path before photodissociation or photo-ionization by solar radiation occurs. In order of increasing extension, we have the following sequence: CH (concentrated near the nucleus); OH ; NH and λ 4050 group; CN and C_2 . The ionized molecules CH^+ , CO^+ , and N_2^+ extend into the tail, but are observed in the head also, in the close neighborhood of the nucleus. Our knowledge of the photodissociation and photo-ionization mechanisms of cometary molecules is still very limited and vague. According to the Franck-Condon principle, a continuous absorption from the ground state, leading to the dissociation of the molecule will be present only if the nuclear distance r_e' in the upper electronic state is appreciably larger than that (r_e'') of the ground state. Cometary molecules may also be dissociated by absorption of solar light in a predissociation region of their spectrum. Accordingly some predictions may be made with respect to the spectral regions of solar radiation that may dissociate specific molecules whose spectra have been analyzed in detail. In the case of C_2 , for example, an excited electronic state exists about 6 volts above the ground state; this excited level has a nuclear distance, r_e' , much larger than r_e'' . Accordingly the absorption of solar radiation of wave length shorter than about λ 2000, by C_2 molecules, will lead to their dissociation.⁶ The ionization energy of C_2 is about 12 volts; thus, as indicated by K. Wurm,⁷ the ionization process is negligible for C_2 , as compared with the efficiency of dissociation.

⁶ The dissociation of C_2 molecules may also result from absorption of solar radiation in a predissociation region of the C_2 spectrum; see Herzberg, *Ap. J.*, **89**, 290, 1939.

⁷ *Ap. J.*, **89**, 312, 1939.

It may safely be assumed that the velocities of the various molecules in the comet's head originate mainly in the process of photodissociation of the parent molecules. When the gases occluded in the meteoritic nucleus are given off, they move away from the nucleus with velocities corresponding to their temperature in the nucleus. But the diatomic radicals resulting from the dissociation of these parent gases may move much more rapidly. As was shown by Wurm,⁸ this is illustrated by the extensions of CN and CO^+ . The fact that CO^+ may be driven off in the tail, by light-pressure, at considerable distances from the nucleus, proves that the average lifetime of CO^+ in the field of solar radiation is long. Yet in the head itself, the CO^+ molecules are observed only very near the nucleus, or behind it in the direction of the tail. Since the masses of CN and CO^+ are not very different, their thermal motions cannot be very different. Thus we must conclude that their different velocities near the nucleus—giving rise to their different extensions in the head—result from the photodissociation mechanisms.

Our ideas about the relative abundances of the various molecules are still very vague. The observed intensities depend on the abundances, the oscillator strengths f , and the amounts of exciting solar radiation. We have more or less reliable laboratory values for $f(OH)$ (Oldenberg and Rieke); $f(CN)$ (White); and $f(CH)$ (Dunham and R. B. King); and theoretical values for $f(NH)$ and $f(C_2)$. At present we can say only that the abundances of these five molecules in comets are all of the same order of magnitude. For example, it is true that the OH -bands are very weak compared with those of CN , but $f(OH)$ is also very small compared with $f(CN)$, and the solar radiation is much weaker near $\lambda 3090$ (OH -absorption) than near $\lambda 3880$ (CN -absorption). No f -values are available at present for CH^+ , CO^+ , N_2^+ , OH^+ , and NH^+ , but we may assume that the f -values for these ions are similar to those of the corresponding electronic transitions in the isoelectronic neutral molecules. Certain regions of a cometary head reveal CH -molecules both in the neutral and in the ionized states. We do not know the

⁸ *Zs. f. Ap.*, 9, 62, 1934.

relative oscillator strengths of CH and CH^+ , and no photometric determination has been made of the relative intensities of the CH and CH^+ bands. Hence it is impossible to estimate the average ionization of the cometary CH molecules.⁹ The ionization potentials of CO , N_2 , and CH are respectively 14.1 ± 0.2 , 15.6 , and 11.13 ± 0.22 e.v., corresponding respectively to λ 880, λ 800, and λ 1110. There is no doubt that the Lyman absorption continuum which sets in at λ 912 must be quite strong in the solar spectrum. The ionization limits of CO and N_2 fall close to the Lyman limit, and we should expect that the amount of solar energy available for λ less than 880 A and λ less than 800 A will be extremely small compared with that for the regions of longer wave lengths. The ionization limit for CH falls about halfway between Lyman α (λ 1215.66) and Lyman β (λ 1025.72) and we may also expect the Lyman absorption lines to be of great intensity in the sun and to have extensive wings. How these absorption features and the corresponding complex spectral distribution of the solar radiation affect the ionization of CO , N_2 , and CH is difficult to compute at the present time.

OTHER POSSIBLE METHODS OF IONIZATION

It is interesting to consider the other possibilities of formation of ionized molecules in comets. One such possibility is the photodissociation of a parent molecule AB into a positive molecule ion A^+ and a negative ion B^- . In such a process, the electron affinity of B is an important factor. A single absorption process would suffice to create A^+ from AB , instead of the two absorption mechanisms usually considered ($AB + hv_0 \rightarrow A + B$; $A + hv_0' \rightarrow A^+ + [-e]$). Even if the photodissociation of AB into $A^+ + B^-$ requires shorter wave lengths than the dissociation into $A + B$, this consideration need not be discarded since the difference in wave lengths may shift the dissociation limit outside absorption lines or farther from the Lyman limit. Another possibility that should be considered is that of

⁹ At any rate, the ionization of CH is much less advanced in comets than in interstellar space.

an ionization caused by the impact of electrons ejected from the solar surface. In the emission spectrum of the aurora, which is excited by solar electrons, the negative nitrogen bands of N_2^+ appear strongly. Many laboratory investigations have dealt with this problem, for example, with the appearance of CH^+ ions when methane—which is found in meteorites—is bombarded with electrons. At the present time, these methods of ionization are merely speculations, since so little is known regarding the parent molecules, and since the laboratory data are still incomplete.

Because of the low density and the small extension of the cometary regions common to CH and CH^+ , there is practically no possibility of capture of electrons by CH^+ ions. In other words, once a CH molecule has been able to absorb photoelectrically a solar photon of wave length shorter than λ 1110, there is practically no chance for capture. Hence, great care must be exercised when considering ionization in comets.

Absorption by molecules of CH , CN , and CH^+ is found in another astronomical source, the interstellar gas. The only difference is that the C_2 bands which are strong in comets are absent in interstellar absorption. But this may be explained theoretically.¹⁰ The similarity in constitution between cometary and interstellar gases is simply a consequence of the cosmic abundances of the elements, and of the characteristic physical properties of the molecules.

Actually the problems of molecular formation are quite different in comets and in interstellar gas. In comets the atmosphere is generated by the liberation of gases occluded in the meteorites forming the nucleus; the observed molecules result from the photodissociation of these parent gases, accompanied or followed by ionization. The interstellar molecules result from the association of two atoms.

In closing I wish to emphasize some of the present needs with respect to cometary spectra:

1. Additional laboratory work on the spectra of ionized diatomic molecules (NH^+ , CN^+ , C_2^+), and on the f -values.

¹⁰ *Lick Obs. Contr.*, Series II, No. 3, 1942; *Ap. J.*, **95**, 270, 1942.

2. Additional laboratory work on the electronic spectra of simple polyatomic molecules which may result from the photodissociation of the polyatomic compounds found in meteorites.

3. Additional photometric work to supplement the pioneering research of Bobrovnikoff: brightnesses in various molecular bands or in a spectral region where reflected solar light alone is present; quantitative distributions of various molecules in the head and their variations with heliocentric distance; etc.

4. Observations of cometary spectra in the completely unexplored range of λ beyond 6500 Å.

5. Quantitative microphotometric investigations of intensity distributions among the rotational and vibrational transitions of a specific molecule, of the relative intensities of bands arising in different molecules, and of the variations with heliocentric distance.

6. Additional investigations of the gases occluded in meteorites of various types.

In the field of cometary physics, we are still in the pioneering stage of qualitative work, and a large amount of investigation remains to be done before we can get a clear picture of a cometary atmosphere, of its origin, and of its evolution.

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