4

THE GASEOUS COMPOSITION OF THE SOLAR NEBULA INFERRED FROM DATA OF COMETS AND INTERSTELLAR MOLECULES

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The observations of comets and other primordial objects must be used to deduce the gaseous composition of the solar nebula just before its condensation. Preliminary steps in this direction are reported here.

Recent detection of HDO, HCO^+, and N_2H^+ in dense interstellar clouds has strongly suggested that oxygen, carbon, and nitrogen in the cloud might mainly be in the form of H_2O, CO, and N_2. Since interstellar molecules have been found in the regions of star formation, the nebular gas around the primitive sun could also contain water, carbon monoxide, and nitrogen molecules, besides hydrogen and helium.

Observations of comets have established that their nucleus is a sort of dirty ice. Cometary ion tails are found to contain H_2O^+, CO^+ and N_2^+. The analysis of the ionic composition as well as that of the temperature distribution in the cometary coma by this author (Shimizu 1976 a,b) have endorsed that the impurities in ice in the cometary nuclei are CO and N_2. Recently CO has been detected in the ultraviolet spectra of the Comet West (Feldman and Brune 1976). Comets may be condensed in the outer part of the solar nebula. Consequently, the similarity between the composition of interstellar molecules and comets is not a coincidence (Shimizu 1976b).

Ammonia has also been detected in dense molecular clouds, but its abundance is only 10^{-3} times the total amount of nitrogen. This molecule has, however, a large dipole moment and is much easier to condense than a nitrogen molecule. The relative abundance of NH_3 to N_2 is expected to be much larger in the cometary nuclei than in the interstellar space.

The upper limit of NH_3 in the cometary gas obtained by infrared observations is about 10% in number. Another restriction on the ammonia abundance can be obtained from the analysis of the observed atomic hydrogen velocity, 8 km sec^{-1}, in the ultraviolet observation of cometary halo (Keller 1976). The atomic hydrogen appears to be formed by the dissociative recombination of H_3O^+, the main ionic constituent of cometary ionosphere (Shimizu 1975). If a large amount of NH_3 exists in a cometary atmosphere, however, H_3O^+ will be converted to NH_4^+ by a rapid ion molecule reaction and H atoms with a velocity of 8 km sec^{-1} will disappear. Fig. 1 shows the result of our computation on the ion

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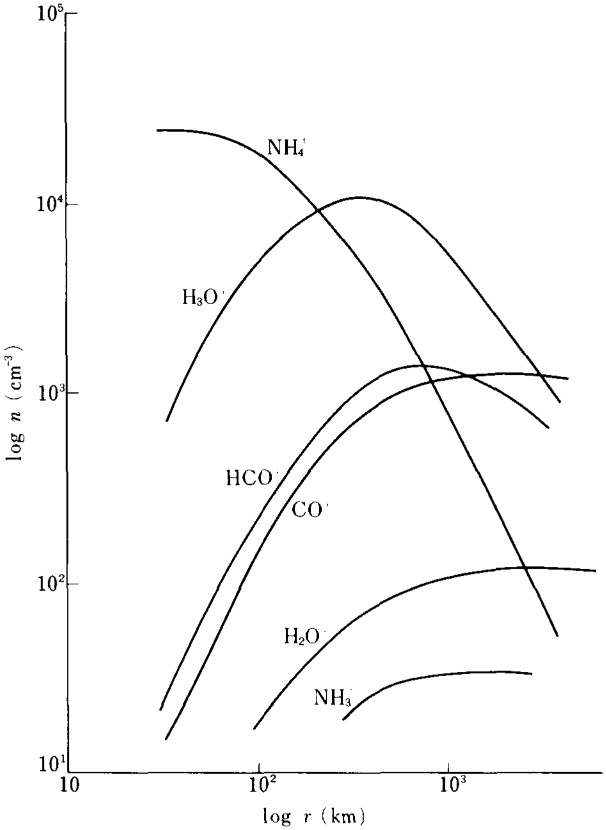

Figure 1. A computer ion distribution in a cometary atmosphere of Bennett type (the molecular production rate : 10^{30} sec^{-1} with a nuclear radius of 10 km). The ratios of H_2O, CO, N_2, and NH_3 are assumed to be 78, 20, 1, and 1, respectively.

distribution in a cometary ionosphere with a composition, H_2O: CO: N_2: NH_3 = 78 : 20 : 1 : 1. Since the concentration of ammonia is large enough to react with H_3O^+ only in the inner region, 10-100 km from the center of cometary nuclei, H_3O^+ is not converted to the NH_4^+ ion outside of 1000 km. The hydrogen atom produced only in this outer region of the ionosphere can escape to the halo region without appreciable collision with other cometary particles. Consequently, if the ammonia abundance is less than 1% of the total atmosphere (namely, of a comparable order as that of the nitrogen molecules), the hydrogen halo around comets can still be interpreted in terms of dissociative recombination of H_3O^+.

The detection of NH_3^+ and NH_2^+ in the laboratory in about 2300 Å is now in progress (Herzberg, a private communication). The detailed analysis of these bands in the cometary ionosphere in future will give a more definite conclusion on the abundance of ammonia. The presence of ammonia in the solar nebula, even in a small amount, is very important for the formation of organic substances in space by a Fischer Tropsch type reaction (Anders *et al.* 1973) and also for the origin of life on the Primitive Earth (Anders *et al*. 1973; Shimizu 1976c). Some theoretical computation on the abundance of CO and N_2 in the solar nebula has so far been performed under the assumption of thermochemical equilibrium, but the appropriateness of such an assumption is not *a priori* justified. The evidences for the gaseous composition of the solar nebula should directly be accumulated from the observations, such as those of comets and other primordial astronomical objects.

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