

23. INTERSTELLAR MOLECULES

Introductory Report

(Wednesday, September 17, 1969)

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1. Introduction

The observation of molecules in the interstellar medium offers an excellent opportunity to specify the physical conditions present there. This must be done through the combined use of theory and observation. In the last few years the advancement in this area has accelerated spectacularly. McNally (1968) reviewed the subject and Spitzer (1968) included molecules in his more general review; these are both excellent references and the reader is referred to them for the development and state of the subject in 1966.*

The subject may be divided into several topics: observations, formation processes, destruction mechanisms, and excitation processes.

2. Observations

Optical observations have been made of (i) a number of electronic transition lines of CH, CH⁺, and CN and, (ii) the as yet unidentified diffuse interstellar lines. There are negative optical searches for the electronic transitions of OH (Herbig, 1968) using conventional instruments and of H₂ (Carruthers, 1967; Smith, 1969) using rockets, but a positive measurement of H₂ in emission has been made in the quadrupole lines using a scanning interferometer (Werner and Harwit, 1968). Perhaps the most sophisticated application of classical techniques is the work by Bortolot and Thaddeus (1969) who added up large numbers of high-dispersion spectrograms and who were able to detect C¹³H molecules. The most complete study of the interstellar line spectrum of a single star is that of ζ Oph by Herbig (1968). Polyatomic molecules were looked for and not found in Herbig's study.

Radio techniques have produced some very exciting results in recent years. The OH radical has been observed in absorption and emission in a variety of excitation conditions. OH in emission has been observed from sources with angular diameters <.01" (assuming that the sources are not coherent so that a Michelson interferometer will resolve them). The resulting brightness temperatures are of the order of 10¹³ K. These sources are believed by some to be protostars where maser action is producing the high brightness temperature (see the Introductory Report by Mezger, p. 336). Litvak (1969) has discussed the models proposed to date.

In the last year three polyatomic molecules have been discovered and they also

* A status report on H₂ by E. E. Salpeter appears as an Appendix to this Report.

exhibit a variety of physical conditions. The molecules are NH_3 (Cheung *et al.*, 1968), H_2O (Cheung *et al.*, 1969), and H_2CO (Snyder *et al.*, 1969). The water molecule is observed in a higher level transition and is apparently also a maser. NH_3 is observed through the inversion transition.

3. The Destruction Mechanisms

To explain the observed molecular abundances one has to consider both the formation and the destruction mechanisms. In this section, we shall discuss destructive mechanisms. Bates and Spitzer (1951) showed that photodissociation in a typical radiation field would give a CH molecule a lifetime of about 1000 yr. A similar calculation by Stecher and Williams (1966) gave about 10^4 yr for OH and NH and about 10^6 yr for CO and CN. Within times of these orders, molecules can be transported only over small distances, so that the existence of formation mechanisms is required at the site where the molecules are observed. For molecules less strongly bound than H_2 destruction will occur through chemical exchange reaction with atomic hydrogen, provided the temperature is above 500 K and the density is normal. With respect to H_2 itself, it was thought for many years that photodissociation had to be done by photons with $\lambda < 850 \text{ \AA}$. These photons are absent in H I regions and the H_2 content of H I regions was therefore considered very high. However, Stecher and Williams (1967) found another kind of destruction mechanism: excitation into electronic states followed by a decay into the vibrational continuum of the ground states. The lifetime of an H_2 molecule is only 10^3 yr in the average radiation field of an H I region. Pre-dissociation has also shortened the expected lifetime of CH (Dressler, 1969; Herzberg and Johns, 1969).

4. Formation Processes

Bates and Spitzer (1951) showed that two-body radiative association of C and H would fail by a factor of 10^4 to produce the observed number of CH molecules. Herbig (1968) found that due to a revised cross section the two-body process produces CH at a sufficiently large rate (provided one has a high density), but more rapid destruction processes discussed by Dressler (1969) nullified this conclusion. Molecular hydrogen cannot form by the two-body process because the stabilizing transition is forbidden. Evaporation from grains has been suggested as a production source, but this leaves the explanation of the origin of the grains in a rather unsatisfactory state.

Formation of molecules on grains, with the grain acting as a third body and taking up the energy of formation in lattice vibration, has been one of the most promising suggestions. However, Knaap *et al.* (1967) showed that the first atom impinging on the grain would evaporate before the second atom arrived, unless the grain were at a much lower temperature than typical conditions indicate. This work assumed that the grains are perfect crystals. A solution to the evaporation problem (Hollenbach, 1969) is to have imperfections in the surface that would trap atoms and bind them more

tightly to the grain. In shielded regions, where the temperature is low and the density is high, this may well be the fastest way to form molecules.

When it looked as if physical adsorption would fail under all conditions, Stecher and Williams (1966) proposed chemical exchange reactions between an incoming atom and one chemically bound to the grain. The process requires an activation energy which the particles can obtain only during cloud-cloud collision or when the grains are driven through the gas at high velocity. There is some evidence that the right molecules are produced in the observed amounts around hot stars where radiation pressure can drive the grains. For example, it seems possible to produce the CN molecule in this way, whereas other mechanisms do not seem capable of doing so.

5. Excitation of Interstellar Molecules

The purpose of this Symposium is to specify and discuss the kinematics and dynamics of the interstellar material. The state of excitation of atoms and molecules may yield information on the physical conditions present and may help in deducing the kinematics. Litvak (1969) has reviewed OH and H₂O masers and discussed in detail the problems associated with their excitation for which chemical, IR, UV, and collisional pumping are possible mechanisms. OH is also observed in thermal emission and absorption as well as in anomalous absorption. When the line formation of the OH radical is understood, it will help us considerably in specifying the physical environments in which this molecule is seen.

The CN radical has rotational levels whose excitation has been used to determine the universal 3 K black-body radiation (Field and Hitchcock, 1966). Other molecules have been used to place upper limits on this radiation at higher frequencies. One of the most interesting observations is that of the H₂CO molecule by Palmer *et al.* (1969), who found it in absorption against the universal black-body radiation, which implies that the molecule must be refrigerated. Townes and Cheung (1969) have suggested a collisional mechanism to accomplish this. The C¹²/C¹³ ratio has been determined as a by-product of the CN work (Bortolot and Thaddeus, 1969) and of the H₂CO work (Zuckerman *et al.*, 1969). This ratio is of fundamental importance for the study of stellar mass loss.

6. Conclusion

The pace of progress is currently so rapid in this field of science that any complete review would have a lifetime measured in months. I hope I have stated some of the reasons for studying interstellar molecules in connection with the study of cosmical gas dynamics.

Note added in proof, June 1970. Since the symposium, H₂ has been found in large amounts in the direction of χ Per by Carruthers. CN has been found at radio wavelengths. CO has been discovered with an interesting isotopic abundance ratio. HCN and HC₃N have been found as well as more states of OH.

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