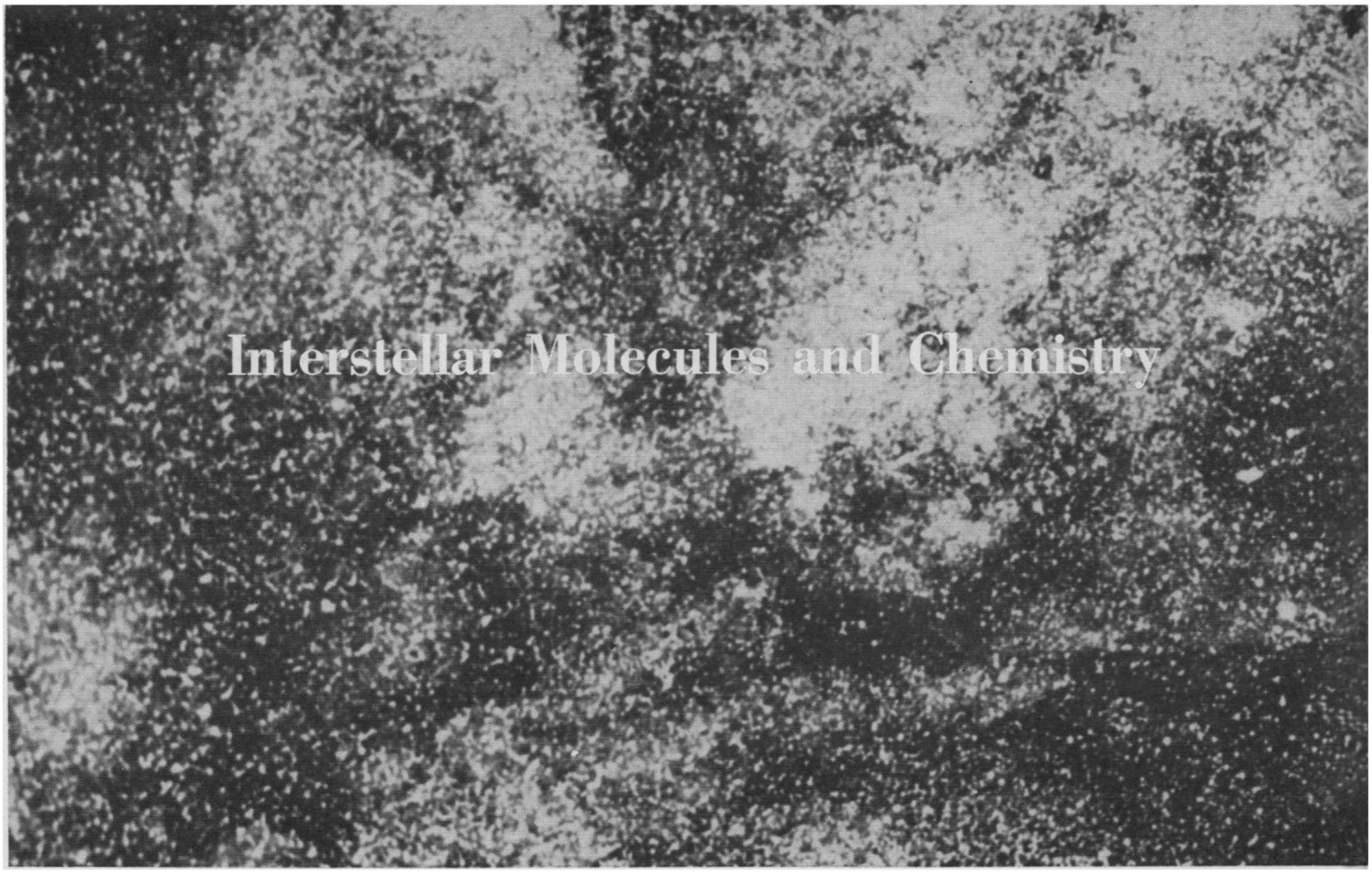


Interstellar Molecules and Chemistry

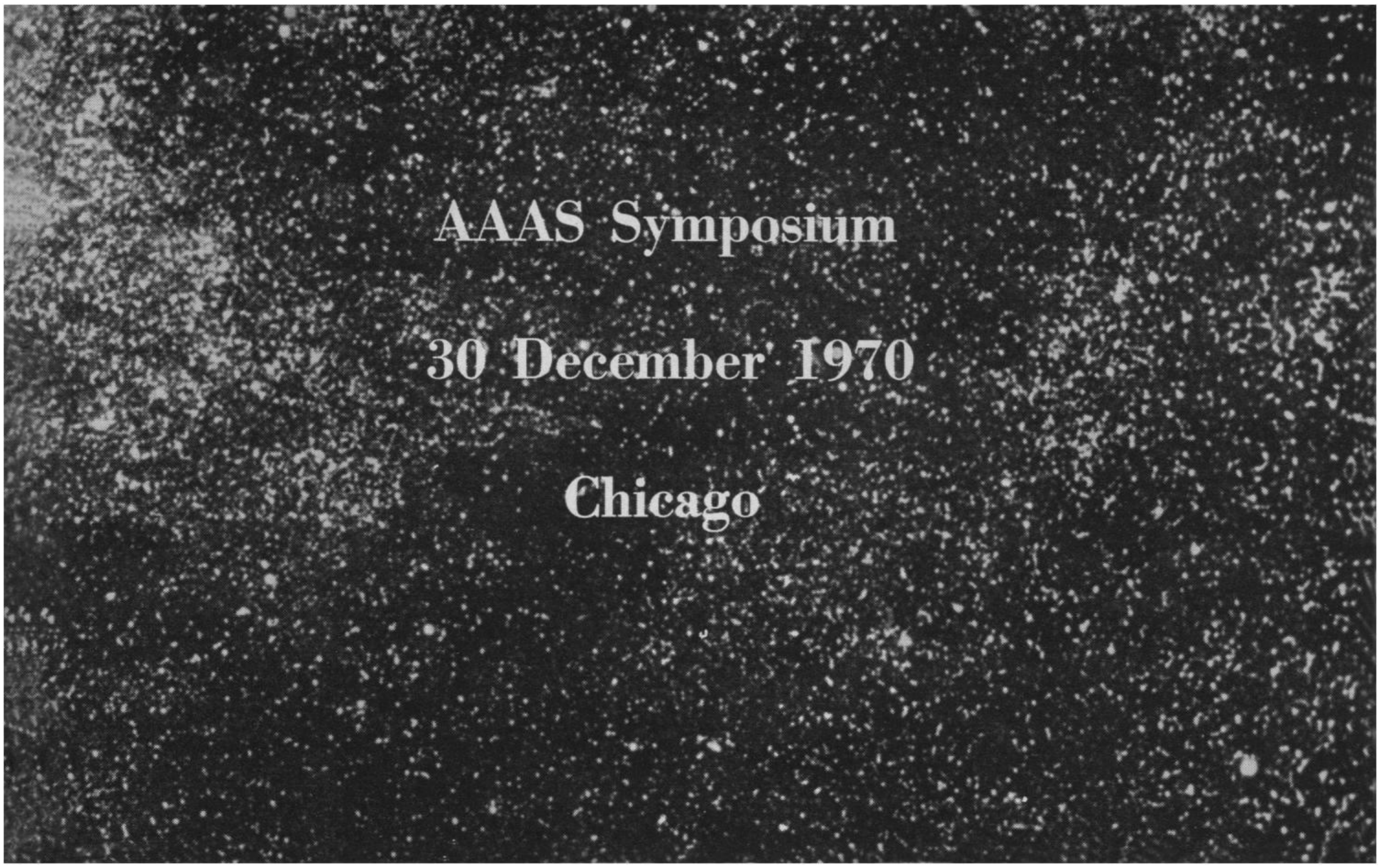
Interstellar space, initially thought to be essentially empty, has turned out to be a complex chemical system. New molecules are being detected by their microwave spectra at a rapid rate. One new diatomic and five polyatomic molecules have been discovered in the last 2 years. With the advent of vacuum ultraviolet observations above the atmosphere, an additional group of molecules can be detected. Molecular hydrogen has recently been found by this technique. At the present time five diatomic and five polyatomic species are known. The most complex molecule thus far is cyanoacetylene, CN–C = C–H.

In the outer half of the galaxy where the sun is located, the total amount of interstellar matter is comparable to the total stellar mass. About 90 percent by number of this material is atomic hydrogen. Within the last 20 years astronomers have been able to show that a continuous exchange occurs between stellar and interstellar matter. Stars are continually being formed from diffuse material in space. As they evolve, matter is ejected from stars to again become part of the interstellar medium. By processes not yet well understood, the diffuse material collects into clouds. Some of these subsequently undergo gravitational collapse attaining stellar densities and temperatures at their center. The surrounding cloud, with much lower densities and temperatures, becomes the primordial nebula in which planetary systems may form.

The collapse of an interstellar cloud is dependent upon the emission properties and the opacity of the material. These features are determined by the molecular composition of the cloud and the larger aggregates—the still uncharacterized interstellar grains—present in the cloud. When star formation has occurred, the development of solid objects, comets through planets, in the surrounding nebulosity must start with the accumulation of the small solid particles. The formation of such particles may be strongly affected by the occurrence of complex interstellar molecules and grains initially present in the clouds. In addition to their effect on star and planet formation, these interstellar species affect the temperature and the large-scale dynamical behavior of the diffuse matter in the galaxy.

A proportionately large fraction of the molecular constituents of space consist of organic compounds. As star and planet formation take place throughout the galaxy, these carbon compounds may play an important role in chemical evolution and the origin of life. This is a phase of the study of the origin of life which has generally been disregarded. However, as more complex organic compounds are found in interstellar space, inclusion of them in investigations of the chemical origin of life becomes more pertinent.

Questions of origin, stability, and subsequent behavior of molecules in interstellar space are important for the variety of astronomical problems associated with stellar and galactic evolution. Physical conditions in space determine types and rates of chemical phenomena that may occur. Table 1 presents the ten cosmically most abundant elements. The average density of atomic hydrogen is about 1 atom per cubic centimeter. The spatial distribution is very irregular, ranging from 0.01 atom/cm^3 in the intercloud region to perhaps $10^6/cm^3$ in the denser clouds. Characteristic dimensions and time scales of the system become important because of the vanishingly small densities. A mean characteristic length for galactic problems is 1 kiloparsec or 3×10^{21} cm. The range of values encountered varies from about 10 kiloparsecs, the



distance of the sun from the center of the galaxy, to approximately 1 parsec (3×10^{18} cm) for some of the dense clouds in which polyatomic molecules tend to be found.

Molecular column densities vary from 10^{13} to 10^{16} per square centimeter. Estimates of volume densities for diatomic molecules are about $10^{-6}/cm^3$ although one estimate yielded $10^{-4}/cm^3$. Polyatomic molecules are found in denser, more opaque clouds, and volume densities from 10^{-2} to 10^{-5} per cubic centimeter have been reported.

The time scale over which substantial changes occur for the interstellar medium as a whole is about 10^8 to 10^9 years. For some of the smaller regions time intervals are probably reduced to about 10^5 years. Because of the larger distances and time intervals chemical phenomena can become important in spite of the low densities. In addition to particle density and time scale, two other parameters of the system which show large-scale variations from terrestrial conditions are the temperature and the importance of ultraviolet radiation. Throughout most of the interstellar medium where molecules are found and for most of the time, temperatures are from 5° to 100°K. For astronomically short times cloud collisions or close passage of a hot star may raise temperatures to about 1000°K. In the more transparent regions ultraviolet radiation below 2500 Å is proportionately very large and photodissociation or ionizatizon become dominant processes. Molecular lifetime against photodissociation are below 1000 years. This period is so short that serious questions are raised concerning the mechanism and place of origin of molecules. Because of the low densities and temperatures the terrestrial important three-body collision process is very inefficient. Proposed mechanisms include two-body radiative association and molecular formation on grain surfaces. Interstellar chemistry can be summed up as being more similar to nonequilibrium laboratory experiments than to the usual thermodynamic approach.

Table 1. Cosmically abundant elements.

Atom No.	Element	Concentration (atom/cm^3)
1	Hydrogen	1
2	Helium	0.1
8	Oxygen	5×10^{-4}
10	Neon	2×10^{-4}
7	Nitrogen	2×10^{-4}
6	Carbon	1×10^{-4}
14	Silicon	2×10^{-5}
12	Magnesium	2×10^{-5}
26	Iron	2×10^{-5}
16	Sulfur	1×10^{-5}

Progress in interstellar chemistry will require a much closer interplay between astronomers and chemists than has hitherto existed. As a step in this direction this symposium will present a review of the relevant astronomical properties of the galaxy and the observations of interstellar molecules. The present state of theories of molecule formation will be described. Other papers to be presented deal with laboratory research in photochemistry and both optical and microwave spectroscopy which have a bearing on the subject of the symposium. The final set of papers will discuss recent laboratory and theoretical investigations in chemical kinetics and surface chemistry which appear to be important for the problems arising from the astronomical observations of the interstellar medium.

This symposium is cosponsored by the AAAS Astronomy and Chemistry Sections.

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