Interstellar Molecules: from the Simple to more Complex

Astronomy is *the* almighty science. "It got physics started by showing the beautiful simplicity of the motion of stars and planets" (Feynman Lecture I. 3-6). Now it is beginning to engulf chemistry by showing exquisite spectra! It has been observationally established that hydrogen in the Universe are more molecular than atomic, over 100 molecules exist abundantly in interstellar space, and molecules are essential for star formation. We here discuss some recent developments starting from the most fundamental H_3^+, which plays *the* pivotal role in interstellar chemistry, to the diffuse interstellar bands, an enigma for astronomers for nearly 100 years, whose carriers are yet to be identified but are surely complex organic molecules.

H_3^+: A Tracer of the Cosmic Ray Ionization Rate in Diffuse Clouds

Benjamin J. McCall, *University of Illinois at Urbana-Champaign*

H_3^+, the simplest polyatomic molecule, plays a key role in dense interstellar clouds as the initiator of ion-molecule chemistry. The detection of H_3^+ in *diffuse* interstellar clouds came as a surprise, however, and suggested a serious (factor of ≥10) problem in the simple model of diffuse cloud chemistry. In particular, this observation raised questions as to the applicability of laboratory measurements of the H_3^+ dissociative recombination rate to interstellar conditions. We have recently measured the dissociative recombination rate of rotationally cold H_3^+ ions in an ion storage ring, and observed H_3^+ in a large sample of diffuse clouds (including that towards ζ Persei). This combination of new laboratory measurements and astronomical observations has eliminated two of the primary uncertainties in the chemical model, and implies a previously unrecognized and significant enhancement in the cosmic-ray ionization rate in the diffuse interstellar medium.

Central Molecular Zone: the Treasure House of H_3^+

Takeshi Oka, *University of Chicago*

With a super-massive black hole at the core, the region near the Galactic center is the hub of activity. Emissions from radio to X-rays and the densities of stars and gas all peak in the region. It also harbors the Central Molecular Zone (CMZ), a region of radius ~ 200 pc which has the highest concentration of molecules in the Galaxy. Our infrared spectroscopic observations in the last five years have shown that sightlines toward the CMZ have H_3^+ column densities that are ~ 10 times higher than the highest observed in the Galactic disk.

Using this richness of H_3^+ with its unique characteristics as an astrophysical probe, a new category of gas with high temperature (~ 250 K) and low density (~ 100 cm^{-3}) has been revealed in the CMZ. Our observations by the UKIRT, Subaru, and Gemini South and their analyses suggest that the gas is ubiquitous and has a high volume filling factor in the CMZ. The relation between this newly found gas and previously known, i. e., the cold (~ 50 K) and high density (≥ 10^4 cm^{-3}) gas observed by radio emission of CO and other molecules, the hot (10^{4-6} K) gas with high electron densities (~ 10 cm^{-3}) observed by radio-wave scattering, and the ultra-hot (10^{7-8}K) gas observed by X-rays is speculated.

Masers as Probes of Interacting Supernova Remnants and Massive Star Formation in the Nuclear Disk of the Galaxy

Farhad Yusef-Zadeh, *Northwestern University*

OH(1720 MHz) and methanol masers are now recognized to be excellent probes of interacting supernova remnants with molecular clouds as well as massive star formation. To better understand the unusual star formation activity in the Galactic center, we use these two classes of masers to study prominent on-going star forming regions. Given the low efficiency of star formation and discrepant value of dust and gas temperatures, we argue that the enhanced cosmic ray electrons impacting molecular clouds have important implications in star formation activity in this region.

UV/Optical Observations of Diatomic Molecules in Diffuse and Translucent Clouds

Daniel E. Welty, *University of Chicago*

We will discuss observations of optical/UV absorption from the diatomic molecules CH, CN, CO, C_2, OH, and NH in sight lines characterized by total visual extinctions less than about 3 magnitudes.
While initial detections of most of these molecules were made many years ago, more recent observations have yielded more accurate abundances in a wider variety of environments — sampling somewhat thicker clouds in our Galaxy and molecular material in several external galaxies. We will explore what these various molecular species — individually and collectively — can tell us about the structure and physical conditions characterizing diffuse and translucent molecular clouds.

Molecular Anions in the Laboratory and in Space

Michael C. McCarthy, *Harvard University*

The importance of negative ions (anions) in astronomy was demonstrated in 1939 by Rupert Wildt who showed that H^- is the major source of optical opacity in the solar atmosphere, and therefore the material which one mainly sees when looking at the sun and similar stars. It is remarkable that in the many years since, during which nearly 130 neutral molecules and 14 positive molecular ions have been found in astronomical sources, no molecular anion has been identified. During the same period of time, more than 1000 molecular anions have now been studied in the laboratory at low resolution, but for only two diatomics, OH^- and SH^-, have rotational spectra been obtained. On the basis of recent experiments, a third negative molecular ion has been detected in the radio band in the laboratory, and, for the first time, in two well-known astronomical sources as well: the molecular envelope of IRC+10216 and in the dense molecular cloud TMC-1. The new anion is a surprisingly molecule — the hexatriyne anion, C_6H^-, a carbon chain which is larger than nearly all the neutral molecules that have been found, and larger than all the cations. The present work suggests that a variety of other molecular anions may now be detectable in the laboratory and in space, and that some of these may be considerably easier to detect than one might suppose.

A Quest to Reveal the Signatures of Aromatic Compounds in Space

Robert J. McMahon, *University of Wisconsin, Madison*

I will describe investigations from our laboratory that illustrate how a perspective in organic chemistry can contribute to the study of important chemical problems in molecular spectroscopy and astronomy. It is remarkable, in light of the current interest in astrochemistry, that the existence of aromatic compounds in space remains an open question. In collaboration with several research groups, we have obtained laboratory rotational spectra for key organic species that will enable the critical astronomical observations that are needed to address this question. Observational data directed at the astronomical detection of *o*-benzyne in CRL 618 will also be described.

Diffuse Interstellar bands: Ubiquitous Large Molecules in Diffuse and Translucent Clouds

Donald G. York, *University of Chicago*

Diffuse interstellar bands are a set of hundreds of unidentified features that are too broad to be from interstellar ions or atoms.

Some 20 specific suggestions for molecules that could give rise to such bands have been made, but all fail stringent spectroscopic tests. For a variety of reasons, they are thought to be molecules of 20-50 atoms, yet unseen in any Earth-based laboratory. Progress on categorizing the bands and on identifying their location of origin in space will be reported, based on extensive survey using the 3.5-meter telescope at Apache Point observatory. The major results so far include a separation of the bands into two types, one associated with molecular hydrogen and one associated with atomic hydrogen, and a small number of excellent correlations between bands or between one band and another interstellar species. The major, 80 year old mystery of the origin of the bands remains unsolved.