

is a comprehensive campaign to further our understanding of fundamental ion-neutral reactions at low temperatures and low densities.

Electrons Make up the Opposition

While ions and neutrals are reacting and combining in interstellar clouds to form larger and more complex molecules, the positively charged ions are under a constant threat to be destroyed by free electrons. When an electron and a positively charged molecular ion “recombine” a lot of energy is set free – typically more energy than the molecule can absorb – and therefore it breaks apart. This process is of great consequence for models of interstellar chemistry, as it represents a natural and ubiquitous counterpart to the formation of larger molecules in ion-neutral reaction networks. In order to study the electron-ion recombination under interstellar conditions a cold electron beam apparatus will be installed at CSR, the so-called electron cooler. To achieve the utmost control over the collision process, the electrons are produced via the photoeffect by a laser beam that is directed at a liquid nitrogen-cooled substrate. The emitted electrons are focused and collimated into a beam that is merged with the ion beam inside the CSR. With this innovative technique collision studies between electrons and ions can be carried out with unparalleled precision.

Combining Modern Experimental Techniques to Shed Light onto the Chemistry of Interstellar Space

The interplay and combination of modern methods in atomic and molecular physics will allow for detailed laboratory experiments of interstellar processes in the near future. The goal of the molecular physics group at MPIK is the preparation of molecular ions in their lowest rotational and vibrational states, and the analysis of individual reactions on a state-selective level. The CSR represents the ideal tool for these groundbreaking activities, and the combination of electron cooling, neutral atom beams and laser spectroscopy will open up a new and fascinating perspective on the onset of chemistry in interstellar space.

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MAX-PLANCK-GESELLSCHAFT

Molecules in Space:

Laboratory Astrophysics



MAX-PLANCK-INSTITUT
FÜR KERNPHYSIK

Molecules in Space:

Laboratory Astrophysics at the Max Planck Institute for Nuclear Physics

The chemistry of interstellar space is one of the most active fields of research in astronomy. Modern telescopes aim specifically at unraveling the molecular composition of the universe, and they provide detailed information about interstellar abundances of molecules like water or organic compounds. It is likely that the emergence of life on Earth is intrinsically linked to the formation of biologically relevant molecules in space. To understand the complex chemistry of interstellar clouds, molecular reactions at extremely low temperatures and densities are studied in the laboratories of the Max Planck Institute for Nuclear Physics (Max-Planck-Institut für Kernphysik, MPIK).

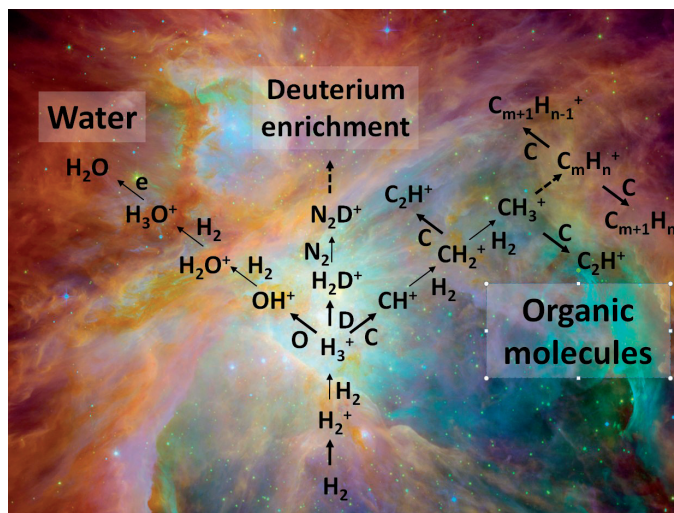
Chemical Reactions under Extreme Conditions

The chemistry of interstellar space differs significantly from chemistry as we know it on Earth. In space molecular reactions occur at cold temperatures down to $-263\text{ }^\circ\text{C}$, only ten degrees from absolute zero. Moreover, the densities in many interstellar environments are so low that months or years may pass between individual reactions. Therefore, highly reactive compounds can exist that would have no chance of survival under terrestrial conditions. On the other hand, owing to the low temperatures, there is very little chemical energy available to overcome reaction barriers and to activate processes in interstellar clouds. Thus many reaction pathways that we consider efficient under terrestrial conditions are effectively closed in space.

Ionized Molecules React More Rapidly

Despite the extreme conditions in space there are very active chemical networks that lead to the formation of complex molecules. The key to this surprising diversity are reactions between charged atoms and molecules (ions) and neutral reaction partners. These ion-neutral processes usually have no reaction barriers and hence they proceed at rapid rates

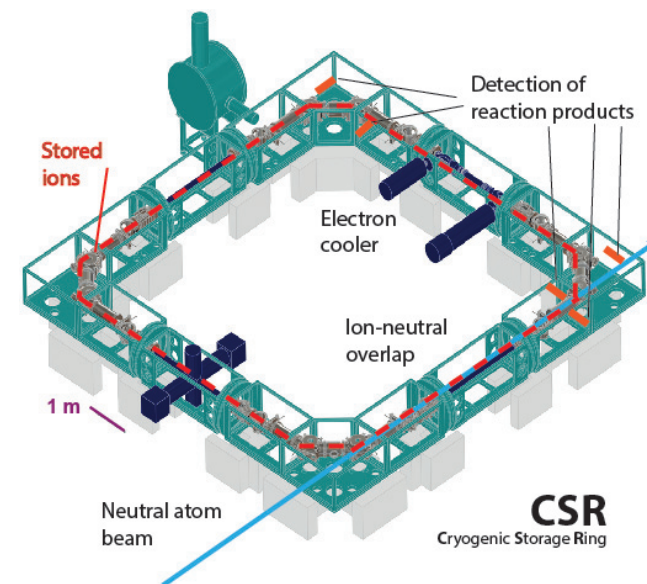
even at very low temperatures. To simulate these reactions in the laboratory requires sophisticated setups, as both collision partners are very reactive and have to be prepared carefully before the process of interest can be studied under well-defined conditions. To this end the molecular physics group at the Max Planck Institute for Nuclear Physics operates a variety of ion traps utilizing different trapping principles.



Excerpt from a chemical network of an interstellar cloud. Shown are reaction pathways that lead to the formation of water and organic molecules through ion-neutral processes.

The CSR – an Ultracold Racetrack for Molecular Ions

The Cryogenic Storage Ring (CSR) represents a very special type of ion trap that is unique in the world. In this instrument molecular ions are stored on a closed orbit of 35 m circumference by the use of electrostatic fields. The inner vacuum chambers of the CSR will be cooled to temperatures below $-263\text{ }^\circ\text{C}$ by a closed-cycle liquid helium cryostat, which will facilitate very long storage times and an ultra-high vacuum of 10^{-16} atmospheres (10^{-13} mbar). In this ultra-clean environment even the most reactive molecular ions can be stored for minutes or hours. The long storage times will permit the molecules to adjust and come into equilibrium with the low ambient temperature. Consequently, the CSR will allow for experiments under true interstellar conditions.



Overview of the Cryogenic Storage Ring (CSR) with experimental sections for neutral atom injection and electron cooling.

Neutral Atoms at the Onset of Chemistry

The path towards polyatomic molecules like water (H_2O) or organic compounds starts with reactions between ions and neutral atoms. While almost all elements on Earth come in molecular form, in interstellar space often atomic species are much more abundant. Gaining a good understanding of ion-atom reactions is therefore of paramount importance for models of interstellar chemistry. To address these topics, a new type of neutral beam setup is currently developed at MPIK. This dedicated experiment will begin with the creation of intense negative beams of hydrogen (H^-), carbon (C^-) or oxygen (O^-) anions. The ions will be neutralized by a very strong continuous laser field and the resulting neutral beam is injected into one of the straight sections of the CSR. In this section ions and neutrals are overlapped with the same velocity to engage in chemical reactions at well-defined collision energies. The reaction products are collected by single-particle detectors at strategic spots in the CSR neutral beam section. The experiment will permit us to measure even slow chemical reactions – and sometimes count reaction products individually – under true interstellar conditions. The goal of the ASTROLAB project at MPIK