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Evolution of interstellar matter in molecular clouds

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Composition of gas and dust in molecular clouds gives the initial condition of the chemistry of planetary matter, because stars and planetary systems are made from those interstellar matter. Firstly, I will review observational studies of the molecular clouds in radio and infrared wavelengths. Secondly I will introduce recent observation of molecular cloud cores, in which molecular abundance evolves as the core collapses gravitationally. Thirdly, I will review theoretical studies of molecular evolution in clouds, especially the models of gas-dust interactions.

I will review the chemical composition and evolution of interstellar matter in molecular clouds. Composition of gas and dust in molecular clouds gives the initial condition of the chemistry of planetary matter, because stars and planetary systems are made from the interstellar matter. Chemical processes revealed in the studies of interstellar matter could also be applicable to the evolution of planetary matter in the formation stages of the solar system.

Spectroscopic observations in radio and infrared wavelengths found as many as 100 molecular species in the gas phase, which include stable and well-known species on earth,such as water and ammonia, very reactive species such as molecular ions and radicals, and strange molecules such as carbon chains. Radicals and carbon chains are abundant because of the low temperature and low density in clouds. Molecular evolution in clouds are triggered by the ionization via cosmic rays, and proceeds mainly through ion-molecule reactions. Chemical reaction network models with ion-molecule reactions successfully reproduce the typical abundances of 80% of the observed species. On the other hand, chemical composition of dust and icy mantles are observed mainly in infrared wavelengths. Various species such as water, carbon monoxide, and methanol are found so far. Recently, ISO found that CO2 ice is also ubiquitous in molecular clouds. Abundances of water, CO2, and methanol are much higher than predicted by the gas-phase reaction network model. Chemical reactions on grain surfaces must play important roles in the production of these species.

So far, I have described the averaged chemical composition in molecular clouds. Molecular clouds have, however, very inhomogeneous structure; they are made of filaments, clumps, and cores. A star is formed via gravitational collapse of a core, once the internal pressure of the core become smaller than gravitational force because of the decay of turbulence and/or dissipation of magnetic fields. Detailed observations of star-forming cores via radio interferometer have revealed that molecular abundances evolve as a core collapses. In the central region of prestellar cores, which are high density starless cores, abundances of CO is lower than in the outer regions. Many gaseous species are adsorbed onto grains because of the low temperature and high density in the core. Depletion of these gaseous species affects the chemical reaction network in the gas-phase; species such as N2H+ and NH3 are more abundant in the central region than in the outer regions. Once a star is formed in the core, ice mantles evaporate because dust is heated by the protostar. Observation of these protostellar cores enables us to estimate the composition of icy mantles in molecular clouds. Desorbed molecules are also transformed to various species via gas-phase reactions there.

These observations show that chemical composition of interstellar matter evolves not only via gas-phase reactions but also via grain surface reactions and chemical interaction between the gas phase and the grain surfaces. Although theoretical models include these gas-dust interactions and succeed in reproducing some of the observed species, there are still various uncertainties concerning grain-surfaces processes, such as migration timescale and evaporation rates of molecules. Finally, I will review the discussion on the formulation of the grain-surface reactions.