

Theory of Self-induced Desorption of Molecules from Cold Dust Surface

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The observations of interstellar molecular clouds show the presence of various species of molecules in the gas phase. Recent observations have revealed the existence of complex organic molecules and terrestrial-type organic species such as methyl formate and dimethyl ether in cold dense cores and pre-stellar cores. On the other hand, it has been pointed out that the molecules in the gas must have been lost from the gas phase by accretion onto dust surfaces in the time shorter than the life time of dense cold clouds. This is called a freeze-out paradox. The accretion timescale is $\sim 10^9/n(\text{H})$ yrs, where $n(\text{H})$ is number density of hydrogen. This indicates that there must be some desorption mechanism to maintain the observed gas-phase abundances. Several mechanisms have been proposed so far such as temperature elevation by grain-grain collisions (d'Hedecourt et al., 1982; Schutte & Greenberg, 1991; Shalabiea & Greenberg, 1994), heating by cosmic ray, X ray and UV photons (Leger et al., 1985, Ivrev et al. 2015), and so on.

We propose a new mechanism that is necessarily associated with exothermic reactions of molecules on grain surfaces even in cold environments like cold dense cores of molecular clouds. This mechanism consists of three steps that occur on the grain surface: (1) formation of new molecules by an exothermal grain-surface reaction, (2) heating of the dust surface due to release of the heat of formation, and (3) desorption of the newly formed molecules into the gas phase.

We formulate the desorption probability of molecules newly formed by exothermic reaction by calculating the temperature distribution on the grain surface as a function of the distance from the reaction site and time. Our formula of desorption probability P is a function of heat of formation Q , desorption energy E_d of a molecule from a substrate, and molecular weight μ of a desorbing molecule. We compare P with the experiments for reactions of various Q , E_d , and μ for three substrates of oxidized HOPG, nonporous amorphous water ice, and amorphous silicate. Here, we used the compilation of the experimental data by Minissale et al. (2016). We also show a method developed for the comparison of our theory with the experiments. Discussion is given on the comparison of our theory with other two theories of desorption (Garrod et al., 2007; Minissale et al., 2016).

Keywords: Astrochemistry, Molecular cloud, Grain-surface reaction, Desorption