From Interstellar Ices to Polycyclic Aromatic Hydrocarbons
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Ion Irradiation of H_2-Laden Porous Water Ice Films: Implications for Interstellar Ice

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Comparison of the infrared spectra obtained in the laboratory from ultraviolet photolysis of methanol-water ice mixtures with the astronomical spectra of WL5 toward the Ophiuchus cloud complex, led Sandford, **Allamandola** and Geballe (1993) to assign the weak absorption feature observed at 4141 cm^{-1} to solid molecular hydrogen embedded in H_2O-rich interstellar ice. The authors suggested that solid H_2 is produced from cosmic ray or ultraviolet processing of interstellar ice containing H-bearing precursor molecules such as methanol or ammonia. They estimated frozen hydrogen to be three times more abundant than solid CO in this particular line of sight.

Incorporation of gas-phase H_2 by adsorption in porous icy mantles can be another source of condensed interstellar H_2. In a cold molecular cloud with $\sim 10^5$ H_2 cm^{-3}, an H_2 molecule arrives at the surface of a 0.1-μm-sized, ice-covered dust grain once every few seconds (Tielens 2005). At 10 K, H_2 can diffuse into the pores of the ice mantle and adsorb at high-energy binding sites, loading the ice with hydrogen over the lifetime of the cloud. Irrespective of the origin, the H_2-laden interstellar ices are continually impacted by galactic cosmic rays and by stellar winds in clouds with embedded protostars. The energy deposited by such impacts can release the adsorbed H_2 back into the gas phase, i.e. impact desorption or sputtering. We recently reported on a new synergistic process of ion-induced enhanced adsorption, where molecules from the gas phase are incorporated into the film when irradiation is performed in the presence of ambient pressure (Shi et al. 2009). The ratio of the ion and gas impingement rates, ϕ, is a key parameter that influences ion-enhanced gas trapping by the ice film. Such interplay between ion-induced ejection and adsorption can be critical to the gas-solid balance in the ISM.

To understand the effects of cosmic ray impacts on interstellar icy grains immersed in H_2 gas, we have irradiated porous water ice films loaded with H_2 with 100 keV H^+. The ice films were exposed to H_2 gas at different pressures following deposition and during irradiation. A net H_2 loss was observed during irradiation due to competition between ion-induced sputtering and gas adsorption. The initial H_2 loss cross-section, 4(1) $\times$ 10^{-14} cm^2, was independent of film thickness, H_2, and proton fluxes. In addition to sputtering, irradiation also closes nanopores, trapping H_2 in the film with binding that exceeds physical absorption energies. As a result, an average of 2-4 % H_2 is retained in the ice following irradiation to high fluences. We find that the trapped H_2 concentration increases with decreasing ϕ, the ratio of ion to H_2 fluxes, suggesting that as high as 8% solid H_2 can be trapped in interstellar ice by cosmic ray or stellar wind impacts. Additionally, we will discuss the effects of the presence of H_2 in radiation chemistry of water ice, particularly the observed suppression in H_2O_2 synthesis.

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