Radiation Chemistry on Solar System Icy Bodies: Laboratory Simulations for Pluto and Other Transneptunian Objects

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The outer Solar System (beyond 20 AU) is populated with icy bodies that are continuously exposed to various forms of radiation, including high-energy photons and cosmic rays. This radiation can drive chemistry in the surface ices of these bodies even in extremely cold conditions. This energetic processing of the ice results in the formation of new reactive ions and radicals that lead to the formation of new molecules, some of which are large, complex, and refractory. Laboratory experiments used to simulate the conditions on these icy bodies can provide insight into this chemistry. Much progress has been made in the laboratory toward understanding the chemistry of energetically processed ices (N_2, CH_4, CO) relevant to the surfaces of outer Solar System bodies (Bohn et al. 1994; Moore & Hudson 2003; Hodyss et al. 2011; Kim and Kaiser 2012), but significantly less progress has been made in understanding the refractory materials produced.

The exploration of radiation chemistry on icy bodies known to have surface deposits of N_2, CH_4, CO, and other simple molecules becomes especially relevant with the impending mid-2015 encounter of NASA's New Horizons spacecraft with Pluto and its satellites. UV and near-IR spectroscopy of the surfaces of Pluto and Charon with spatial resolution ~10 km will provide the first close-up measurements of the native ices, their irradiation products, and their spatial distribution.

We conducted a series of laboratory experiments involving the UV-photolysis of low-temperature (15 K) N_2-, CH_4-, and CO-containing ices (in relative proportions of 100:1:1, respectively), i.e., a mixture analogous to the surface of Pluto, with a focus on the analysis of the refractory material left after the sample is warmed and ices have sublimed. We utilized several chemical techniques; infrared (IR) spectroscopy was used to analyze both the resulting ice (from 15 K through sublimation) and the refractory residue (at 300 K), while the refractory residue at room temperature was also analyzed with X-ray absorption near-edge structure (XANES) spectroscopy and gas chromatography coupled with mass spectrometry (GC-MS).

Despite starting with extremely simple ices dominated by N_2, UV-photolysis results in the production of refractory material with more complex oxygen- and nitrogen-bearing organic molecules. Infrared spectra of the refractory material indicate the presence of O–H, N–H, C≡N, and C=O functional groups. These bands suggest the presence of alcohols, carboxylic acids, ketones, aldehydes, amines, and nitriles. XANES spectra of the material indicate the presence of aromatic or olefinic carbons, nitriles, carboxyl groups, urea, and nitriles, which are consistent with the IR data. XANES data also provide atomic abundance ratios for the bulk composition of these residues. The organic residues are extremely O- and N-rich, having ratios of N/C ~ 0.5 and O/C ~ 0.3. Finally, GC-MS data reveal that the residues contain urea as well as numerous carboxylic acids, some of which are of interest for prebiotic and biological chemistries.

References

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