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## The Chemistry of Pluto and its Satellites

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Pluto's bulk composition and the composition of the surface layers hold clues to the origin and evolution of a number of other Solar System bodies of comparable size in the region beyond Neptune. The July 14, 2015 flyby of the Pluto system with the New Horizons spacecraft afforded the opportunity to corroborate and greatly improve discoveries about the planet and its satellites derived Earth-based studies. It also revealed extraordinary details of the surface and atmosphere of Pluto, as well as the geology and composition of Charon and two smaller satellites. With a mean density of  $1.86 \text{ g cm}^{-2}$ , the bulk composition of Pluto is about two-thirds anhydrous solar composition rocky material and one-third volatiles (primarily  $\text{H}_2\text{O}$  in liquid and solid states) by mass, the surface is a veneer of ices dominated by  $\text{N}_2$ , with smaller amounts of  $\text{CH}_4$  and  $\text{CO}$ , as well as limited exposures of  $\text{H}_2\text{O}$  ice (considered to be "bedrock").  $\text{N}_2$ ,  $\text{CH}_4$ , and  $\text{CO}$  occur as solid solutions at temperature-dependent mutual concentrations, each component being soluble in the others. Frozen  $\text{C}_2\text{H}_6$  as a minor component has also been identified. Sublimation and recondensation of  $\text{N}_2$ ,  $\text{CH}_4$ , and  $\text{CO}$  over seasonal (248 y) and Milankovich-type megaseasons ( $\sim 3 \text{ My}$ ) result in the redistribution of these ices over time and with latitude control. Solid  $\text{N}_2$  is found in glaciers originating in higher elevations and flowing at the present time into a basin structure larger than the State of Texas, forming a convecting lens of  $\text{N}_2$  that overturns on a timescale of order 10 My. The varied colors of Pluto's landscape arise from the energetic processing of the surface ices in processes that break the simple molecules and reassemble complex organic structures consisting of groups of aromatic rings connected by aliphatic chains. When synthesized in the laboratory by UV or electron irradiation of a Pluto mix of ice, this material, called tholin, has colors closely similar to Pluto. The Pluto ice tholin analog contains carboxylic acids, urea, ketones, aldehydes, amines, and some nitriles. The largest satellite, Charon has density  $1.70 \text{ g cm}^{-2}$  and it is about 3/5 anhydrous solar composition rock, with the remainder in  $\text{H}_2\text{O}$  ice. The surface  $\text{H}_2\text{O}$  ice is infused in some way with  $\text{NH}_3$ , probably as a hydrate, distributed nonuniformly, but to some degree related to geological structures. Pluto's atmosphere is  $\text{N}_2$ ,  $\text{CH}_4$ , with  $\text{CO}$ ,  $\text{C}_2$ -hydrocarbons,  $\text{HCN}$ , and other molecules in trace but detectable amounts. The atmosphere supports a complex haze structure with about 20 discrete layers, and suspected clouds. The haze is presumed to be made of aggregates of complex hydrocarbons (tholins) produced by photolysis of the atmospheric gases, and with similar composition to the ice tholins made on the planet's surface. Urea and a suite of carboxylic acids are of interest for prebiotic and biological chemistries.