Inorganic Chemistry on Jupiter and Its Satellites

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Although Earth and Jupiter are members of the same solar system, they exhibit key differences. Earth is small and relatively close to the Sun, but Jupiter is much larger and further from the sun. Jupiter and its satellites comprise a complex system, sometimes likened to a miniature solar system.[1] These fundamental differences mean that inorganic chemistry on Jupiter takes place under conditions often unfamiliar to us on Earth.[2-4] For example, pressure regimes common on Jupiter and its satellites range from about 2 Mbar in Jupiter's deep atmosphere[4] to roughly 1 nbar for the atmosphere of Io, a large satellite.[5] Furthermore, because Jupiter is composed mostly of hydrogen, chemistry on that planet takes place under reducing conditions.[2,3] By examining the behavior of inorganic species under these extreme conditions, we can gain insight into chemistry unfamiliar on Earth.

Although the outer layer of Jupiter contains mostly molecular hydrogen and atomic helium, the variations within the atmosphere are caused by condensation or reaction of inorganic compounds.[2,3,6-8] Three distinct layers of condensation have been detected at intermediate depths in the atmosphere.[3] From top to bottom, the three cloud layers consist of NH_3, NH_4SH and H_2O. Photochemistry of simple hydrocarbons takes place in the upper atmosphere,[2,3,9] and photochemical cycles stemming from NH_3, PH_3 and H_2S have been established.[2,3] The nitrogen cycle results in the production of hydrazine aerosols.[2] The phosphorus (Figure 1) and sulfur cycles produce solid particles which are thought to give Jupiter its colorful appearance.[1-3] The detection of CO_2 should be hampered due to its reduction[2] by H_2, but relatively high levels of this gas have been detected since Comet Shoemaker-Levy 9 impacted Jupiter in July 1994.[9]

In the interior of Jupiter, the pressure becomes enormous. Near the 2 Mbar level, hydrogen is dissociated and ionized into metallic hydrogen.[4] This region is still fluid, as shown by density and magnetic field measurements.[1,4] Recent experiments on Earth have allowed laboratory observation of the insulator-metal phase transition in hydrogen.[10-12] The transition is apparently continuous, which disagrees with the theoretical prediction of a first-order transition.[4,12] Further modifications are needed in the equation of state for these results to be incorporated into models of Jupiter.[4]

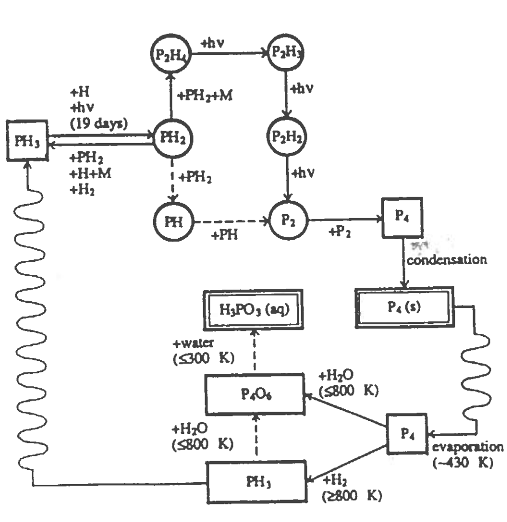

Figure 1

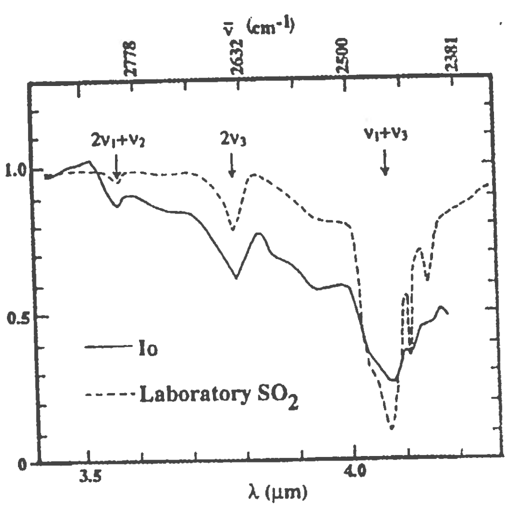

Figure 2

Jupiter's four main (Galilean) satellites have been known since the earliest days of the telescope.[5] They are among the largest and most widely varied satellites in the solar system.[1] In 1979, the Voyager missions discovered active volcanoes on Io, the innermost Galilean satellite.[13] Measurements from the Voyager missions indicated sulfur volcanism, but the Galileo Orbiter's better instrumentation revealed higher temperatures.[14] Some lava flows are in excess of 1700 K, which indicates that high-Mg silicates are responsible for volcanism.[5,14] There is evidence for SO_2 frost on the surface of this satellite[3,5,15,16] (Figure 2), and other sulfur compounds[5,16] give Io its colorful appearance.[16] A very tenuous atmosphere of SO_2 has been detected,[5,17] along with the unexpected finding of neutral atomic species, including Na, K, Cl, S and O, escaping from the satellite in the form of large cloudlike features.[3,5,17]

Much interest has been devoted to the next Galilean satellite, Europa, which likely has a global subsurface layer of liquid water or soft ice.[5,18] Several lines of evidence point to the existence of this ocean, including magnetic measurements, the movement of large crustal blocks between the Voyager and Galileo missions, and the near absence of craters on the surface.[5,16,18] Recently, it was shown that hydrated H_2SO_4 is a major component of Europa's surface. Sulfur on Europa is likely contained in three chemical reservoirs: H_2SO_4, SO_2 and polymerized sulfur.[18] Exchange of sulfur between these species takes place by radiolysis.[18,19] These results indicate that chemistry on Europa's surface is dominated by radiolysis.[19]

Studying the Jovian system gives us insight into inorganic chemistry under extreme conditions. There are wide temperature and pressure regimes on Jupiter and its satellites, and the atmosphere of Jupiter is strongly reducing. Inorganic species also play critical roles in understanding the Jovian system, including coloration, meteorology and internal structure.

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