

PROPERTIES OF PLANETARY FLUIDS
AT HIGH PRESSURE AND TEMPERATURE

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The outer planets Uranus and Neptune are thought to consist of the "ices" H_2O , CH_4 , NH_3 , and possibly CO , CO_2 and N_2 .¹ The envelopes of these planets, as well as those of Jupiter and Saturn, are composed of H_2 and He .¹ In order to derive models of the interiors of these planets we have been studying the equations of state and electrical conductivities of these molecules at high dynamic pressures and temperatures. This study is timely because of the recent Voyager II flyby of Uranus, which measured the magnetic field distribution and the rotation rate of the magnetic field, which gives the rate of rotation of the interior of the planet.² The gravitational moments derived from the rotation rate put constraints on the mass distribution. Thus, equations of state of representative materials are needed to model the chemical composition. The magnetic field requires information on the electrical conductivities of representative materials to develop dynamo models. The condensed gases in these planets were compressed isentropically starting from very low density and temperature. By virtue of their large masses, however, interior temperatures and pressures are quite large. For Uranus the conditions in the "ice" layer range between 0.2-6 Mbar and 2000-7000 K.³ Shock compression of liquids achieves virtually the same states in the laboratory.

Interest has been generated in the interior of Uranus because of its unusual magnetic field with an offset tilted dipole moment of 0.23 gauss R_U ³, whose dipole axis is tilted about 60° from the axis of rotation and centered at about $0.3 R_U$, where R_U is the radius of Uranus.² Thus, material at substantially larger radii than $0.3 R_U$ must be contributing to the dynamo. This means that data we obtain using our two-stage light-gas gun at pressures up to ~ 2 Mbar and temperatures up to 5000 K are especially relevant for constructing models of the interior.

During the past year we used the fast optical pyrometer developed the previous year to complete shock temperature measurements for N_2 and CH_4 . Nitrogen can exist inside Uranus by virtue of the decomposition of NH_3 , whose shock temperature we measured previously.⁴ The nitrogen temperature data showed that it undergoes a continuous phase transition to a dense, stiff, monatomic, diamond-like phase above 0.3 Mbar and 6000 K. The temperature data allowed us to demonstrate shock-induced cooling (a first), that $(\partial T/\partial P)_V < 0$ in the transition region (as predicted), and the existence of crossing isotherms in P-V space.⁵ The shock-induced cooling is caused by absorption of internal energy by dissociation. Since N_2 at room temperature does not dissociate at static pressures up to 1.3 Mbar,⁶ the transition in the shock-wave

experiments must be temperature-driven. Because of the high temperatures inside Uranus, the same phenomena would be expected there also. Thus, it is quite likely that the lower ice region is composed of stiff, diamond-like H, C, N, O phases. In contrast, our two shock temperature points near 0.4 Mbar and 4000 K for liquid CH₄ are in good agreement with the published prediction, which assumes shocked methane is in the molecular phase.⁷

Electrical conductivities measured for shocked liquid CH₄ show that its conductivity is substantially lower than that of H₂O. Our results for N₂ show that our maximum observed value at 0.6 Mbar is comparable to the maximum conductivity we measured for H₂O, but the conductivity of H₂O is much higher than for N₂ below 0.6 Mbar.

In order to find materials with higher electrical conductivities than observed so far for individual fluids and which may be necessary to derive a Uranian dynamo theory, we have started to investigate fluid mixtures. We have devised a mixture we call "synthetic Uranus," which is based on estimates of the composition of Uranus, proposed to be mostly H₂O and H₂. We have made a liquid with a 4:1 ratio of H to O, corresponding to an equimolar mixture of H₂O and H₂, and also with concentrations of C and N such that the ratios of the concentrations of O to C and O to N correspond to the ratio of their cosmic abundances (7:4 for O to C and 7:1 for O to N).⁸ Three shock-wave equation-of-state points were measured between 0.15 and 0.78 Mbar. This mixture has the same shock P-V curve as H₂O when scaled to the appropriate initial molar volume. This fluid has a relatively high conductivity at ambient. Our preliminary data does not allow us to say that its conductivity is larger than that of water at higher pressures and temperatures. Work is continuing on this point.

Our research plans are to complete our measurements of shock temperatures, emission spectroscopy, and electrical conductivities of the "ices," H₂, and "synthetic Uranus" and to develop techniques to measure the same properties in quasi-isentropically compressed fluids. This technique would cause the specimens to track states closer to the planetary isentropes; that is, at relatively higher densities and lower temperatures than the shock data.

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