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" H₂O, CH₄, NH₃, and possibly CO, CO₂ and N₂.¹ The envelopes of these planets, as well as those of Jupiter and Saturn, are composed of H₂ 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 Rᵤ³, whose dipole axis is tilted about 60° from the axis of rotation and centered at about 0.3 Rᵤ, where Rᵤ is the radius of Uranus.² Thus, material at substantially larger radii than 0.3 Rᵤ 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 N₂ and CH₄. Nitrogen can exist inside Uranus by virtue of the decomposition of NH₃, 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 (dT/dP)ᵧ < 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 N₂ 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 CH$_4$ are in good
agreement with the published prediction, which assumes shocked methane
is in the molecular phase.$^7$

Electrical conductivities measured for shocked liquid CH$_4$ show that
its conductivity is substantially lower than that of H$_2$O. Our results
for N$_2$ show that our maximum observed value at 0.6 Mbar is comparable to
the maximum conductivity we measured for H$_2$O, but the conductivity of
H$_2$O is much higher than for N$_2$ 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 H$_2$O and H$_2$. We have made a liquid with a 4:1 ratio of H to O,
corresponding to an equimolar mixture of H$_2$O and H$_2$, 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 H$_2$O 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," H$_2$, 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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REFERENCES


Connerney, R. P. Lepping, and F. M. Neubauer, "Magnetic Fields at

3. W. B. Hubbard and J. M. MacFarlane, "Structure and Evolution of


