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PROPERTIES OF THE PLANETARY MATERIALS He, SiO$_2$, AND N$_2$ AT DYNAMIC HIGH PRESSURES AND TEMPERATURES


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Résumé - On a mesuré en régime dynamique les propriétés physiques à haute pression et haute température de trois matériaux que l'on pense être des constituants des planètes externes.

Abstract - Physical properties have been measured dynamically at relevant high pressures and temperatures for three materials thought to constitute the outer planets.

The first shock-compression data for liquid He were measured. Using a two-stage light-gas gun, liquid He at 4.3 K and 1 atm was shocked in the range 1.2-16 GPa (12-160 kbar) and double-shocked to 56 GPa. The equation-of-state data are in good agreement with the theory of Ross and Young who used liquid perturbation theory to determine an effective interatomic potential. The calculated temperatures, 1200K at 16 GPa and 2100K at 56 GPa, are comparable to temperatures in the envelopes of Jupiter and Saturn.

SiO$_2$ aerogel is a transparent glass structure with a pore size of 10 nm and a density of 0.13 g/cm$^3$, 20-fold expanded relative to the density of α-quartz. We have obtained Hugoniot data for this material to 15 GPa and 7-fold compression, which is still a 3-fold volume expansion relative to α-quartz. A shock temperature of 10,800K was measured pyrometrically at 6.7 GPa. The data are shown in Fig. 1, plotted with the results for crystalline α-quartz. Equation-of-state data for this material may lead to an understanding of cratering phenomena induced by hypervelocity impact, both because SiO$_2$ is an abundant geological material and because aerogel can be used to diagnose states in other minerals releasing from 100 GPa shock pressures.

Fig. 1 - Equation-of-state and shock temperature data for shocked SiO$_2$ aerogel, initially 20-fold expanded relative to α-quartz. Also shown is the Hugoniot of α-quartz (Ref. 3).
New equation-of-state data were measured for liquid N\textsubscript{2} single- and double-shocked to pressures up to 100 GPa, compressions up to 4-fold over initial liquid density, and internal energies up to 1 MJ/mole.\textsuperscript{4} A new single-shock point at 80 GPa shows that the softening in the nitrogen Hugoniot at 30 GPa is followed by a stiffening at 50 GPa---a shape similar to Hugoniots of materials undergoing phase transitions. The data are shown in Fig. 2, plotted with previous results for nitrogen\textsuperscript{5,6} and carbon monoxide. Three double-shock data points lie above the principal Hugoniot in pressure-volume space. This observation is the first in condensed matter of double-shock pressure greater than single-shock pressure at the same volume, and implies that pressure increases with decreasing temperature at constant volume. These anomalous double-shock points are caused by a continuous phase transition. By comparing the principal Hugoniots of liquid N\textsubscript{2} and isoelectronic CO,\textsuperscript{7} the phase transition is identified as molecular dissociation. Preliminary data show that nitrogen has an electrical conductivity of 10 (ohm-cm)\textsuperscript{-1} at 40 GPa shock pressure, a significant increase from its initial insulating state. Estimated shock temperatures of > 6,000 K\textsuperscript{8} indicate nitrogen is in the fluid phase in these experiments. The temperatures are comparable to those predicted for the interiors of Uranus and Neptune. The dissociation of shocked liquid N\textsubscript{2} and NH\textsubscript{3} suggest that, if nitrogen exists in the outer planets, it exists in more phases than simply NH\textsubscript{3}.

Fig. 2 - Hugoniots for liquid N\textsubscript{2} (triangle at 80 GPa is this work, solid circles from Ref. 6, squares from Ref. 5) and CO (open circles from Ref. 7). The dash-dot curve is extrapolation of low-pressure common curve for both N\textsubscript{2} and CO.

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