
Introduction. The recent flights of Pioneer and Voyager to Jupiter and Saturn, as well as anticipated visits to Uranus and Neptune, have stimulated a renewed interest in the structure of the giant planets. To construct accurate models, it is necessary to explain their observed luminosity, radius, oblateness, rotation rate, and gravitational moments in terms of equations of state for the postulated constituent materials. But efforts have been hampered by a lack of accurate data on the chemical, physical, and thermodynamic properties of constituent materials at the extremely high temperatures and pressures characteristic of planetary interiors. Shock-wave experiments conducted recently at LLNL have provided more accurate equation-of-state, electrical conductivity, and spectroscopic data for many of these materials, and these have led to improved structural models. The giant planets are thought (1,2) to consist mainly of hydrogen, helium, ammonia, methane, and water; and a rocky core of iron, nickel, silicon, and magnesium oxides. Hydrogen and helium are subjected to a very wide range of conditions. From 1 bar at the surface to 45 Mbar and 20,000 K at the Jupiter rock core boundary.

Our shock-wave data has been obtained with a two-stage light-gas gun (3). This device can accelerate a 20-g metal projectile against a target at velocities up to 8 km/s. To achieve conditions comparable to those in the planetary interiors, H₂ (4), CH₄ (5), NH₃ (6), and H₂O (6) must be shocked from the liquid phase. All except H₂O have boiling points below room temperature. Thus, the targets are actually small cryostats, which are expended in each experiment.

Helium. We report results of shock-wave equation-of-state experiments for dense, high-temperature helium. The purpose is to provide data with which an effective intermolecular pair potential can be derived to calculate a theoretical equation of state for helium at extreme conditions. This equation of state will then be used with our recent equation of state for hydrogen (7) to derive a model for the solar Hz-He mixture.

Extensive cryogenic measures are taken to reduce the heat load on the specimen holder in order to collect and keep liquid He at 4 K. Specimen holders (4) are machined from pure Al for high thermal conductivity and wrapped everywhere but over the impact surface with 100 layers of aluminized Mylar for radiation shielding. The impact surface is a mirror to reflect thermal radiation incident in the infrared; that is, the impactor surface is diamond-turned for smoothness and plated with 1000 Å of Au. The solid angle for incident thermal radiation is minimized by placing a liquid-N₂-cooled, cylindrical, Cu "cold tunnel" ahead of the impact surface. The coaxial cables from the shock-wave detectors have a stainless steel outer conductor of 0.5-mm diameter. These cables are thermally anchored to a liquid-N₂-cooled cold-finger in the wall of the target chamber to minimize thermal conduction to the specimen holder. The gun target chamber is evacuated to 10⁻⁵ torr to minimize thermal convection to the specimen holder. With these and other measures a specimen holder can be maintained for 20-30 minutes for the gun firing sequence.

Single-shock compressions of three-fold at 160 kbar have been achieved. These results are in substantial agreement with our theoretical predictions (8). The calculated temperatures range up to 12,000 K. Data for double-shock experiments near 550 kbar will be presented as available. This state has a calculated temperature of 20,000 K, which is comparable to the maximum temperature in the H₂-He layer of Jupiter and exceeds that in Saturn (11,000 K).
SHOCK-WAVE STUDIES OF GIANT PLANET MATERIALS

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Water. Electrical conductivity data for shocked H$_2$O suggests that it is significantly ionized (2H$_2$O$^+$OH$^-$+H$_3$O$^+$) at shock pressures above 200 kbar (6,9). We have developed the capability of single-pulse (10 ns), spontaneous Raman spectroscopy during the shock state. The technique has been applied to H$_2$O at a shock pressure of 70 kbar and a calculated temperature of 370 C. A frequency-doubled Nd:glass laser at 532 nm was used to excite the shocked sample. Stokes radiation emitted at a 90° angle to the exciting laser beam was collected by an f/2 achromatic lens which imaged the sample volume onto the slit of an f/3 flat-field 0.25 m spectrograph. A microchannel plate image intensifier was installed at the focal plane of the spectrograph to increase the brightness of the spectrum which was recorded on film. We observed a broad OH-stretch band 690 cm$^{-1}$ in width, significantly less than observed in the same sample unshocked (904 cm$^{-1}$). The narrowing may be caused by the breaking of weak intermolecular OH hydrogen bonds. These bonds are substantially responsible for the very wide OH-stretch band (10). We are planning to extend the measurements to 200-300 kbar and 1500-2000 K to look for OH$^-$ and/or H$_3$O$^+$ ions. Water is transparent up to shock pressures of 300 kbar (11).

We are also measuring the temperature histories of multiply-shocked H$_2$O to test the suggestion from double-shock equation-of-state and electrical conductivity data that the temperature of quasi-isentropically compressed H$_2$O is very close to that of shocked H$_2$O. For these experiments we are using the 6-channel optical pyrometer used previously for shock temperature measurements at LLNL (12). A new pyrometer is being fabricated to make shock temperature measurements on cryogenic liquid specimens.

References.

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