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FLUIDS AT HIGH DYNAMIC PRESSURES AND TEMPERATURES

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ABSTRACT

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Electrical conductivity data for shocked liquid nitrogen, Hugoniot data for liquid air, shock temperatures for liquid ammonia, and double-shock equation-of-state data for Al are discussed.

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I. INTRODUCTION

Nitrogen undergoes a continuous dissociative phase transition above 30 GPa shock pressure [1]. To obtain more information on this transition electrical conductivities of liquid nitrogen shocked to 20-50 GPa were measured. In order to investigate the effects of molecular impurities on this transition and to investigate the properties of mixtures, the Hugoniot equation of state of liquid air was also measured. The equation of state of NH_3 is of importance for models of the outer planets Uranus and Neptune. NH_3 is one of the "ices" thought to be a major component of these planets at interior pressures above 20 GPa and temperatures greater than 2000 K [2]. We have measured the shock temperatures of liquid NH_3 at 48 and 61 GPa.

Aluminum was used as the equation-of-state reference material in shock-impedance-match experiments performed in proximity to underground nuclear explosions and discussed elsewhere in these proceedings [3]. In those experiments Hugoniot data were obtained for Mo and Cu in the 1.5-2.5 TPa region. In order to test the theoretical equation of state for Al at the highest pressures available with our two-stage light-gas gun, double-shock experiments were performed on Al to 330 GPa. Al is most probably in the fluid phase in these experiments because Al melts on its Hugoniot at 150 GPa [4,5].

II. EXPERIMENT

Shock waves were generated by means of a two-stage light-gas gun. The specimen holders for the electrical conductivity experiments used the electrode and trigger system described previously for water experiments [6].

For these liquid nitrogen experiments the electrode configuration was adapted to the cryogenic specimen holder described previously [7]. For conductivities below $0.1 \text{ (ohm-cm)}^{-1}$ a constant voltage measuring circuit was used [8]. For higher conductivities a constant-current circuit was used [6]. The liquid air Hugoniot data were obtained using the same system as for liquid nitrogen experiments [7]. The coolant was liquid N_2 . The air specimens had a fractional chemical composition of 0.781 N_2 , 0.210 O_2 , and 0.009 Ar and were at 77.1 K initially. The liquid NH_3 shock temperature measurements were performed with a fast multichannel pyrometer using photomultiplier tubes. The coolant was cold N_2 gas [6]. The double-shock Al experiments were performed using Ta impactors and specimens which were a composite of Al and a Ta anvil. The first-shock state was obtained by measuring impactor velocity and impedance-matching the Hugoniots of Al and Ta [9]. The second shock state was obtained by measuring the shock velocity in the Ta anvil.

III. RESULTS

Electrons are expected to be the dominant-conduction mechanism in nitrogen and the electrical conductivity data were interpreted using a semiconductor model. Calculated shock temperatures [10] were used for this analysis, which yielded an effective electronic energy gap of 5 eV in the

shock pressure range 20-30 GPa. The electronic carrier concentration is of order $2 \times 10^{18} \text{ cm}^{-3}$ at 20 GPa. Thus, at shock pressures below the dissociative transition at 30 GPa, the carrier concentration corresponds to about one carrier per 10^4 N_2 molecules. The energy absorbed in this carrier activation is insufficient to affect the equation of state, as was assumed previously for this range [10]. Analysis of the conductivity data in the transition region above 30 GPa will be completed when our shock temperature measurements are performed in this region.

The Hugoniot data for liquid air are plotted in Fig. 1 as shock pressure versus molar volume. Also shown are the fits to the Hugoniot data for nitrogen [1] and oxygen [7]. The air point at 28 GPa is in the molecular region for N_2 and is intermediate between the N_2 and O_2 data, as expected. The air point at 65 GPa is in good agreement with both the nitrogen and oxygen data. All three fluids, as well as carbon monoxide are apparently approaching a common limiting molar volume at high shock pressures.

The shock temperature data for liquid NH_3 at 4000 K agree to within ten percent with theoretical calculations that neglect molecular dissociation-ionization. From electrical conductivity data at 7-28 GPa [11], NH_3 is known to ionize at high shock pressures and temperatures. Because of the small difference between the temperature data and theory, the energy absorbed in ionization is insufficient to affect significantly the thermal equation of state. A detailed paper on this NH_3 work will be published elsewhere [12].

Additional results for shocked molecular fluids are discussed elsewhere in these proceedings, including the spontaneous Raman spectroscopy of shocked water [13] and the emission spectroscopy of shocked benzene [14].

Equation-of-state data for Al shocked to 160 GPa and double-shocked to 300 GPa are shown in Fig. 2, plotted as shock pressure versus relative volume. Also plotted in Fig. 2 is the 300 K-isotherm calculated by McMahan [15] using electron band theory. This figure illustrates how the thermal pressure of the double-shock point is significantly less than the thermal pressure on the Hugoniot at the same volume. In a plot of pressure versus mass velocity, the double-shock point lies on the mirror reflection of the principal Hugoniot. The "mirror reflection" approximation to reshock curves and release isentropes is common at lower pressures. Deviations from this approximation are expected at higher pressures, but as yet we have not observed such deviations.

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Figure Captions

Fig. 1 Hugoniot data for liquid air. Also plotted are fits to the data for liquid nitrogen and oxygen.

Fig. 2. Double-shock data point (open circle) for Al. The solid circle is the first shock state.

Figure 1

Figure 2