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COMPRESSED LIQUID NITROGEN

D. C. Hamilton
A. C. Mitchell
W. J. Nellis

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ELECTRICAL CONDUCTIVITY MEASUREMENTS IN SHOCK COMPRESSED LIQUID NITROGEN

D. C. Hamilton, A. C. Mitchell and W. J. Nellis

Lawrence Livermore National Laboratory
Physics Department
Livermore, California 94550

ABSTRACT

The electrical conductivity of shock compressed liquid nitrogen was measured in the pressure range 20-50 GPa using a two-stage light-gas gun. The conductivities covered a range 4×10^{-2} to $1 \times 10^2 \text{ ohm}^{-1} \text{ cm}^{-1}$. The data are discussed in terms of a liquid semiconductor model below the onset of the dissociative phase transition at 30 GPa.

INTRODUCTION

Recent dynamic experiments indicate that liquid nitrogen begins to undergo a phase transition to the monatomic state at shock pressures of 30 GPa.^{1,2} This is evidenced by an increase in the shock wave compressibility and is attributed to the combined effects of shock compression and heating. Below the transition region nitrogen is believed to remain diatomic and follow a law of corresponding states.³

Nitrogen is a major constituent in explosives, comprising about 30 molar percent of the detonation products.⁴ Nitrogen, in its molecular form or as ammonia, is also represented to a significant extent in the interiors and atmospheres of the outer planets.⁵ Issues for both planetary conditions and detonation phenomena are the importances of dissociation, phase separation and semiconduction. Electrical conductivity measurements can provide information on the partitioning of energy between internal degrees of freedom like electronic excitation and thermal energy and enable an estimate of the degree of ionization and mechanisms of charge transport. For these reasons we performed the first reported electrical conductivity measurements of liquid nitrogen over a pressure range of 20-50 GPa.

EXPERIMENT

The experiments were performed using a two-stage light-gas gun. The diagnostic system⁶ and sample preparation² are described elsewhere. The liquid samples were condensed from reagent grade nitrogen gas with measured impurity concentrations of oxygen and argon not exceeding 0.30 and 0.015 mole percent, respectively. Final pressures of the shocked samples were inferred from impedance matching using the known equations of state of aluminum⁷, tantalum⁷ and nitrogen².

The electrical conductivity was determined by methods outlined in references 8-11. A constant-voltage circuit was used for the measurements of conductivity below $0.1 \text{ ohm}^{-1} \text{ cm}^{-1}$ and constant-current circuit for higher conductivity values. In the former case a shock wave traversing perpendicular to two parallel electrodes situated in the sample acted as a switch and resistor of an RC circuit. The magnitude of the signal compared to signals produced by several standard resistors gave the resistance of the final state of the sample. In the constant-current circuit a capacitor was discharged through current-limiting resistors and a shunt resistor (across the electrodes) just prior to the shock arrival at the electrodes.¹¹ The shunt was chosen to match the expected resistance of the sample for maximum sensitivity. For both types of circuits and all experiments the resistances of the cells were calibrated using liquids of known conductivities.

RESULTS AND DISCUSSION

In Figure 1 the electrical conductivity of liquid nitrogen versus shock pressure is shown to cover nearly four orders of magnitude over the shock pressure range 20-50 GPa. Preliminary analysis indicates the shocked fluid behaves as a liquid semiconductor and follows the characteristic form

$$\sigma \sim \exp(-E/KT)$$

conductivity in the molecular region. Calculated shock temperatures³ were used for this analysis. The slope of the logarithm of the electron conductivity versus the reciprocal of the calculated temperature gives an activation energy of about $2.7 \text{ eV} \pm 1.2 \text{ eV}$ which corresponds to a semi-conducting effective band gap of 5.4 eV. This suggests a density-dependent narrowing of the band gap from its value at 77°K of around 9 eV, which is based on optical absorption measurements.¹² Proceeding with a semiconductor description we calculate the carrier concentration¹³ $n = 2.4 \times 10^{18} \text{ cm}^{-3}$ at 20 GPa, where we have used Ross's calculated temperature of 4800°K and a band gap of 5.4 eV. This is about one carrier per 10^4 nitrogen molecules. The effective mobility, assuming a form $\mu_{\text{eff}} = \sigma/ne$, where σ is the electrical conductivity (4×10^{-2}) and e the electronic charge, is $0.1 \text{ cm}^2/\text{volt-sec}$, which is more than 10 times its value measured at 77°K.¹⁴ The electronic collision time $\tau = m\sigma/ne^2$, is $6 \times 10^{-17} \text{ s}$, where m is the free-electron mass. Using an electron thermal velocity v_T of $4.7 \times 10^7 \text{ cm/s}$, the mean free path, $\lambda = \tau v_T$, is 0.3 Å. This estimate is less than a molecular diameter and is characteristic of a percolation or Brownian-type charge transport process. In this model electrons are described as being excited into extended states near a mobility edge.¹⁵

Extrapolating the calculated temperatures to higher shock pressures, which probably overestimates the temperatures because of the neglect of molecular dissociation, the conductivity increases dramatically from its constant-slope value on a ' $\log \sigma$ vs $1/T$ ' plot indicating a large increase in carrier mobility and/or carrier density. Further interpretation of the data is awaiting shock temperature measurements.

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Fig. 1