RECEIVED BY COSTI

JUL 22 1985

CONF-850730-27

UCRL-92921
PREPRINT

SHOCK TEMPERATURE MEASUREMENTS IN AMMONIA

H. B. Radousky, A. C. Mitchell,
W. J. Nellis and M. Ross
Lawrence Livermore National Laboratory
Livermore, CA 94550

This paper was prepared for submittal to
Proceedings of the APS Topical Conference
on Shock Waves in Condensed Matter - 1985
Spokane, WA
July 22-26, 1985

July 1985

Lawrence
Livermore
National
Laboratory

This is a preprint of a paper intended for publication in a journal or proceedings. Since changes may be made before publication, this preprint is made available with the understanding that it will not be cited or reproduced without the permission of the author.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

SHOCK TEMPERATURE MEASUREMENTS IN AMMONIA

DE85 014810

H. B. Radovsky, A. C. Mitchell, W. J. Nellis and M. Ross

Lawrence Livermore National Laboratory
Livermore, CA 94550

ABSTRACT

Our first shock temperature measurements on a cryogenic target are reported for NH_3 . A new fast optical pyrometer and a cryogenic specimen holder for liquid NH_3 were developed to measure shock temperatures of 4400 and 3600 K at pressures of 61 and 48 GPa. These conditions correspond to those in the ice layers in Uranus and Neptune. The shock temperature data are in reasonable agreement with an equation of state based on an intermolecular potential derived from NH_3 Hugoniot data.

INTRODUCTION

Temperature measurements on shock compressed materials can be extremely valuable for diagnosing the physics which occurs at these extreme conditions. They provide a much more stringent test of theoretical models than the Hugoniot alone, and give information on the partition of energy between internal energy and phenomena which might be occurring, such as dissociation-ionization. In this paper, we report shock temperatures of ammonia at 48 and 61 GPa, which represents our first such temperature measurements on liquid samples which require cryogenic specimen holders.

The work on ammonia was motivated by its relevance to planetary models. Such models of the outer planets generally consist of three layers.^{1,2} The outer layer is assumed to be H_2 and He, probably in proportions similar to the solar mixture, a He mass fraction of 0.22. The middle layer might be either He and metallic H in Jupiter and Saturn, or H_2O , NH_3 , CH_4 , and possibly CO, CO_2 and N_2 "ices"³ in Uranus and Neptune. The innermost layer is a rocky core. The condensed gases were compressed isentropically starting from low, atmospheric density and temperature. By virtue of the large masses of these planets the interior temperatures and pressures are quite high. In the outer layer of Jupiter, for example, they range up to about 400 GPa (4 Mbar) and 10,000 K. The conditions in the outer layer of Uranus and Neptune range up to about 20 GPa and 2000 K, while the middle layer ranges up to about 600 GPa and 7000 K. Shock compression of liquids achieves virtually the same states in the outer planets as isentropic compression starting from the gas phase.

Jan

EXPERIMENTAL RESULTS

The shock temperatures in NH_3 were measured using a six channel optical pyrometer. The technique is based on observing the thermal radiation emitted from electrons behind the shock front, which are in thermodynamic equilibrium with the lattice. This radiation can escape in the forward direction through the unshocked and still transparent material. The experimental design is shown in Fig. 1. The pyrometer consists of six photomultiplier tubes which can measure the light intensity emitted from the shock heated sample at six different wavelengths ranging from 254-830 nm. Including the ultraviolet portion of the spectrum allow measurements up to 30,000 K, which is important for studying many of the materials of current high interest such as N_2 ⁴ and He.⁵ The output of the photomultiplier tubes is then recorded on fast oscilloscopes and film.

For shock temperature measurements on most planetary fluids, cryogenic specimen holders are required. Our holder uses the cryogenic design used previously for Hugoniot experiments.⁶ For NH_3 experiments a variation using a cold N_2 -gas flow system⁷ was employed to avoid handling liquid NH_3 . A sapphire window was placed at the rear of the sample cavity to permit light emitted from the shock front to exit the holder and be sent to the pyrometer by a turning mirror. Light is observed from a specimen area of 2 mm^2 on axis.

An oscillogram from the 600 nm channel of the pyrometer is shown in Fig. 2. The signal is flat as the shock traverses the sample, and the double shock off the shapphire window is clearly seen as a rise in light intensity. The magnitude of the voltage signals are related to actual intensities through an in-situ calibration against a known source of spectral radiance. The data for the two sets of measurements are shown

Fig. 1 Schematic diagram of the experimental configuration. Light from the shocked NH_3 escapes through the transparent sapphire window.

Fig. 2 Oscillogram from the 600 nm channel of the pyrometer. Record from shot NH_3 #2 ($T = 4,800 \text{ K}$).

Fig. 3 Spectral radiances for the two NH_3 experiments. Curves are the best graybody fits.

in Fig. 3. The temperature was determined by least square fitting the data to a Plank greybody spectrum,

$$n(\lambda) = \frac{\epsilon C_1}{\lambda^5} (e^{C_2/\lambda T} - 1)^{-1}, \quad (1)$$

where $n(\lambda)$ is the spectral radiance, λ is the wavelength, $C_1 = 1.19 \times 10^{-16} \text{ W} - \text{me}^2/\text{Sr}$, $C_2 = 1.44 \times 10^{-2} \text{ me-K}$ and ϵ is a wavelength independent emissivity. The least squares fits to the data are shown in Fig. 3. The results, plotted as temperature vs pressure are shown in Fig. 4 and tabulated in Table 1, along with other relevant parameters. The pressure was obtained by measuring U_I and the method of shock impedance matching. The C and S parameters used in the impedance matching are tabulated in Table 2.

Table 1. Shock Temperatures and Emissivities for NH_3

Shot	T_0	ρ_0 (g/cm ³)	U_I (km/s)	P (GPa)	V/V_0	T (K)	ϵ
NH_3 #3	230 K	0.6933	5.60	47.6	0.414	3550 ± 200	0.95
NH_3 #2	230 K	0.6933	6.56	61.3	0.389	4380 ± 200	1.00

1 GPa = 10 kbar
 $V_0 = 24.6 \text{ cm}^3/\text{mole}$

Table 2. C and S Parameters used to obtain the pressure in shocked NH_3 using the method of shock impedance matching

	NH_3^{a}	Al^{b}	Ta^{b}
C (km/s)	3.211	5.386	3.293
S	1.201	1.339	1.307

^a Ref. 7. Valid for $4.0 < U_p < 7.6$ km/sec

^b Ref. 11.

Fig. 4 NH_3 shock temperature plotted as a function of pressure. Solid line is a calculation discussed in the text.

Fig. 5 Best fit to the Hugoniot data is shown for NH_3 . The pair potential derived from the fit was used to calculate the temperatures in Fig. 4. A good fit to the data was obtained over the entire pressure region.

DISCUSSION

The solid line shown in Fig. 4 is the result of a calculation using fluid perturbation theory and is based on an intermolecular potential derived from a fit to the Hugoniot data. The form used was an exponential-sixth power potential,

$$\phi(r) = \frac{\epsilon}{k} \left\{ \left[\frac{6}{\alpha-6} \right] \exp [\alpha(1-r/r^*)] - \left[\frac{\alpha}{\alpha-6} \right] \left[\frac{r^*}{r} \right]^6 \right\} \quad (2)$$

The parameters chosen to best fit to the Hugoniot data were $\alpha = 12.5$, $\epsilon/k = 150$ K, and $r^* = 3.85$ Å. The Hugoniot data^{7,9-10} and the resulting fit are shown in Fig 5. The calculations include contributions from rotation and vibration.

Comparison of the calculated temperatures with the experimental results in Fig. 4 shows that the model used is in reasonably good agreement with the data. The small deviation of 10% at the highest pressure maybe an indication of an additional absorption mechanism at these high pressures. Previous electrical conductivity measurements⁹ on ammonia have show that it becomes conductive in the range 7-28 GPa. The mechanism proposed to explain the high conductivity was molecular dissociation-ionization. The relatively small difference between the measured temperatures and those calculated using this non-dissociative model suggests that dissociation is not sufficient to affect the equation of state in a dramatic way. Including dissociation-ionization in the

model would have the effect of lowering the calculated temperatures in the direction of better agreement with the experimental data.

ACKNOWLEDGEMENTS

This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48, with partial support from the U.S. National Aeronautics and Space Administration under contract No. 83-033.

We acknowledge P. C. McCandless for fabricating the cryogenic specimen holders, C. D. Wozynski, K. Peterson and R. F. Schuldheisz for firing and maintaining the two-stage gun, and I. Miller for fabricating the projectiles.

REFERENCES

1. W. L. Slattery, *Icarus* 32, 58, (1977).
2. W. B. Hubbard, and J. J. MacFarlane, *J. Geophys. Res.* 85, 225 (1980).
3. D. J. Stevenson, *Annu. Rev. Earth Planet Sci.* 10, 257, (1982).
4. W. J. Nellis, W. C. Holmes, A. C. Mitchell, and M. van Thiel, *Phys. Rev. Lett.* 53, 1661, (1984b).
5. W. J. Nellis, W. C. Holmes, A. C. Mitchell, R. J. Trainor, G. K. Governo, M. Ross, and D. A. Young, *Phys. Rev. Lett.* 53, 1248, (1984a).
6. W. J. Nellis and A. C. Mitchell, *J. Chem. Phys.* 73, 6137 (1980).
7. A. C. Mitchell and W. J. Nellis, *J. Chem. Phys.* 76, 6273 (1982).
8. M. Ross, *J. Chem. Phys.* 71, 1567 (1979).
9. M. I. Kovel, Ph.D. thesis, Lawrence Livermore National Laboratory report UCRL-51367, pp. 90.
10. R. D. Dick, *J. Chem. Phys.* 74, 4053 (1984).
11. A. C. Mitchell and W. J. Nellis, *J. Appl. Phys.* 52, 3363 (1981).

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.