

TABLE IV. Shock wave data for liquid nitrogen^a at 75°K.

Shock vel. (km/sec)	Particle vel. (km/sec)	Pressure (kbar)	Relative vol. (V/V_0)	Dural shock vel. (km/sec)
2.58±0.02	0.90±0.09	19±2	0.653±0.037	6.07±0.07
2.97±0.02	1.11±0.05	27±1	0.628±0.016	6.24±0.04
3.53±0.01	1.51±0.04	44±1	0.570±0.010	6.58±0.03
4.19±0.02	1.97±0.03	68±1	0.531±0.008	6.97±0.03
5.09±0.02	2.54±0.02	106±1	0.501±0.004	7.48±0.02
5.50±0.02	2.78±0.02	126±1	0.494±0.005	7.71±0.02
5.93±0.03	2.99±0.12	146±6	0.495±0.020	7.91±0.09
6.66±0.03	3.62±0.07	198±4	0.457±0.010	8.48±0.05
6.98±0.08	3.72±0.09	213±5	0.468±0.014	8.58±0.07
6.85±0.04	3.89±0.05	219±3	0.432±0.008	8.71±0.04
7.34±0.04	4.05±0.07	244±5	0.448±0.011	8.89±0.06
7.52±0.05	4.33±0.07	267±4	0.425±0.010	9.13±0.06
7.52±0.04	4.36±0.15	269±9	0.419±0.020	9.16±0.12
7.59±0.03	4.39±0.12	273±8	0.422±0.016	9.19±0.10
7.43±0.03	4.45±0.08	271±5	0.401±0.011	9.22±0.06
7.73±0.03	4.57±0.10	289±6	0.409±0.013	9.35±0.08
8.17±0.06	4.61±0.09	309±6	0.435±0.012	9.43±0.07
7.92±0.05	4.66±0.11	303±7	0.412±0.014	9.44±0.09
8.36±0.06	4.75±0.08	325±6	0.433±0.010	9.56±0.06
8.51±0.08	4.92±0.05	343±4	0.422±0.008	9.71±0.04
8.48±0.03	5.08±0.11	354±8	0.400±0.013	9.85±0.09
8.80±0.04	5.20±0.09	376±7	0.409±0.010	9.98±0.07
8.92±0.06	5.35±0.12	391±9	0.400±0.014	10.11±0.10

^a Density is 0.820 g/cc.

the data and is

$$U_s = 1.17 \pm 0.17 + (1.72 \pm 0.06) U_p - (0.06 \pm 0.01) U_p^2. \quad (13)$$

There is fair agreement with the data of Walsh and Rice,⁸ and Cook and Rogers.⁹ For shock velocities between 3.50 and 4.75 km/sec Mitchell and Keeler²⁶ obtained a linear relationship which has a larger intercept and smaller slope than expressed by Eq. (11). The reason for this discrepancy is not known. The values of U_s for $U_p = 0$, as determined from Eqs. (11) and (13) are significantly larger than the measured sound speed. Bridgman⁵ found that the liquid freezes at a pressure of approximately 1 kbar at 25°C, which may account for the lack of agreement.

Figure 9 is a $P-V/V_0$ plot showing two concave upward curves corresponding to the two straight lines of Fig. 8. A slight cusp appears at about 164 kbar. A single curve through the data is equally descriptive, considering the quality of the data.

For shocked carbon tetrachloride, Walsh and Rice⁸ observed a slight change in transparency to visible light at about 70 kbar and complete opacity between 130 and 170 kbar. Previous dynamic pressure studies^{27,28} on carbon tetrachloride have found a large increase in electrical conductivity at pressures above 120 kbar. A thorough investigation by Mitchell and Keeler²⁶ revealed measurable conductivity at 69 kbar and very

high conductivity at 164 kbar. Hence, there seems to be a relation²⁹ between the onset of opacity and measurable electrical conductivity at about 70 kbar. In addition the opaqueness and the very high electrical conductivity observed in the 160–170-kbar range may also be related to the change in slope in the U_s-U_p plot at 164 kbar.

The observed behavior of carbon tetrachloride under shock conditions may be the result of the liquid polymerizing in the 70–170-kbar pressure range. The molecular rearrangement occurring in the polymerization process could free ions in sufficient quantity at 70 kbar to produce detectable changes in opacity and electrical conductivity. The change in slope of the U_s-U_p curve at 164 kbar may signal the end of this process, with the upper line corresponding to the new polymer. Based on some calculations³⁰ Mader of this laboratory has suggested that a different chemical species is formed according to the reaction $2\text{CCl}_4 \rightarrow \text{C}_2\text{Cl}_6 + 2\text{Cl}_2$ at pressures near 100 kbar while insignificant amounts of the new substance are formed below 50 kbar.

Another explanation for the change in slope of the U_s-U_p plot at 164 kbar is the following: A pressure-temperature graph of Bridgman's carbon tetrachloride freezing data³¹ and that from the Hugoniot information indicates that the Hugoniot curve crosses into a solid III phase at about 10 kbar. Then near 160 kbar the Hugoniot recrosses the liquid-solid phase

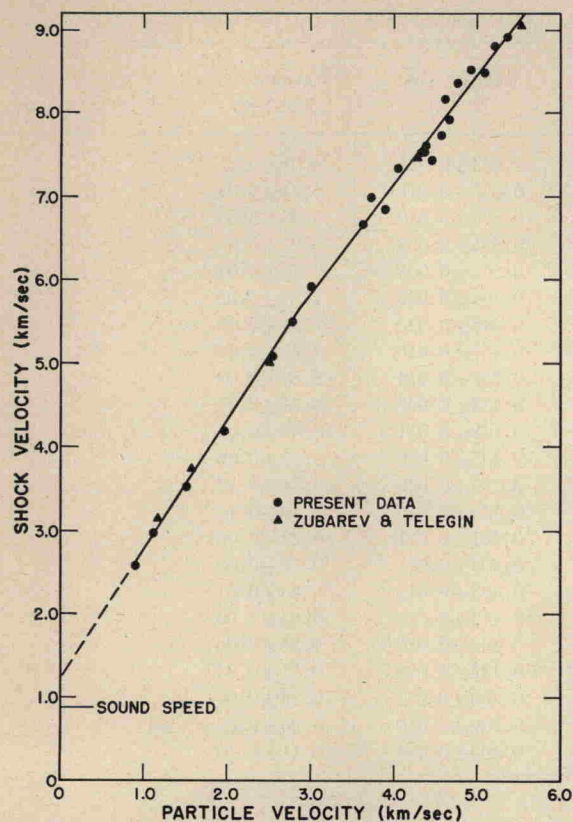


FIG. 10. Shock velocity-versus-particle velocity plot for liquid nitrogen.

line and remains in the liquid state. This particular explanation, however, does not explain the opacity and electrical conductivity changes observed at high pressures.

Temperatures for carbon tetrachloride shocked into

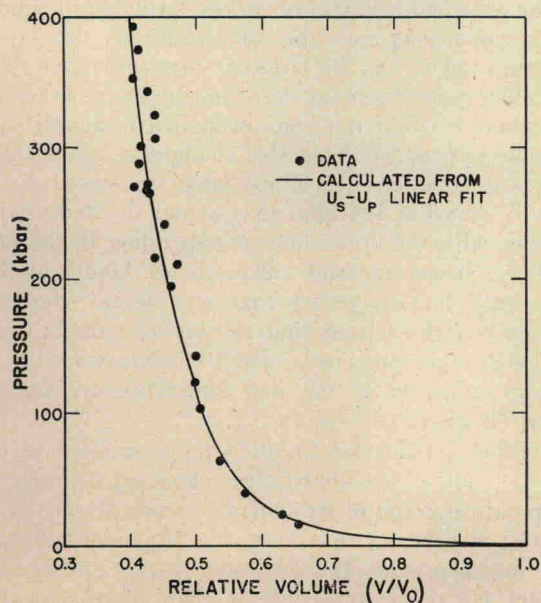


FIG. 11. Pressure-versus-relative volume plot for liquid nitrogen.

TABLE V. Potential parameters used for computing Hugoniot for liquid nitrogen.

Potential form (References)	r^* (Å)	T^* (°K)	n	α
LJD (present work)	4.17	97.5	9	...
LJD (Ref. 10)	4.19	91.5	12	...
LJD (Ref. 36)	4.16	95.9	7	...
LJD (Ref. 37) ^a	4.13	91.5	12	...
LJD (Ref. 35)	4.15	95.0	12	...
exp-6 (present work)	4.00	110.0	...	13.6
exp-6 (Ref. 34)	4.05	120.0	...	13.0

^a Gaseous nitrogen data.

the 70–170-kbar range were calculated to be between 1350 and 3500°K using the Mie–Grüneisen equation of state. Ramsey³² of this laboratory has measured a brightness temperature of 2400°K at 170 kbar. Recently, Voskoboinikov and Bogomolov³³ have reported measuring the brightness temperature of the shock front in carbon tetrachloride over a pressure range of 80–200 kbar. At 170 kbar they measured 2600°K.

A Hugoniot curve computed by Salzman, Collings, and Pings²² from a Lennard-Jones and Devonshire intermolecular potential is located slightly above the experimental Hugoniot curve when plotted in the

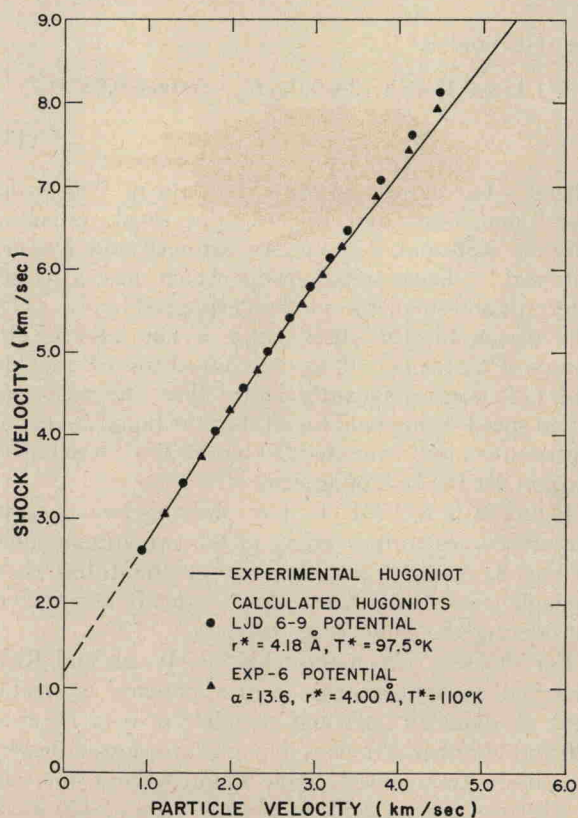


FIG. 12. Experimental and calculated Hugoniot for liquid nitrogen.