

TABLE II. Shock wave data for carbon disulfide.

Initial density (g/cc)	Shock velocity (km/sec)	Particle velocity (km/sec)	Pressure (kbar)	Relative volume (V/V_0)	Dural shock velocity (km/sec)
1.260	2.47±0.01	0.75±0.08	23±3	0.698±0.033	5.93±0.07
1.249	2.41±0.00	0.86±0.04	26±1	0.642±0.017	6.02±0.03
1.251	2.59±0.01	0.86±0.05	28±2	0.668±0.017	6.02±0.04
1.251	2.94±0.01	1.01±0.03	37±1	0.658±0.010	6.16±0.02
1.257	3.06±0.01	1.07±0.03	41±1	0.650±0.010	6.22±0.03
1.263	3.09±0.01	1.08±0.04	42±2	0.651±0.012	6.23±0.03
1.264	3.39±0.01	1.31±0.03	56±1	0.615±0.008	6.43±0.02
1.245	3.43±0.01	1.39±0.02	59±1	0.594±0.006	6.50±0.02
1.272	3.47±0.01	1.40±0.03	62±1	0.597±0.008	6.52±0.02
1.260	3.47±0.01	1.42±0.02	62±1	0.590±0.007	6.54±0.02
1.266	3.51±0.01	1.52±0.08	68±4	0.566±0.024	6.62±0.07
1.249	3.53±0.01	1.72±0.02	76±1	0.513±0.007	6.78±0.02
1.249	3.55±0.01	1.81±0.01	80±1	0.491±0.004	6.86±0.01
1.272	3.65±0.01	1.87±0.05	87±2	0.489±0.013	6.92±0.04
1.253	3.62±0.01	1.91±0.02	87±1	0.473±0.006	6.95±0.02
1.251	3.78±0.01	2.13±0.09	101±5	0.436±0.025	7.14±0.08
1.251	4.02±0.01	2.25±0.02	113±1	0.442±0.004	7.26±0.01
1.257	4.18±0.00	2.28±0.02	120±1	0.454±0.004	7.31±0.02
1.264	4.20±0.01	2.33±0.04	124±2	0.446±0.009	7.35±0.03
1.248	4.40±0.01	2.56±0.03	141±2	0.420±0.007	7.56±0.03
1.275	4.86±0.02	2.77±0.03	172±2	0.430±0.006	7.80±0.03
1.253	4.80±0.01	2.83±0.02	170±1	0.410±0.005	7.83±0.02
1.258	5.23±0.02	3.20±0.08	211±5	0.388±0.015	8.20±0.06
1.251	5.20±0.02	3.31±0.06	215±4	0.364±0.011	8.29±0.05
1.251	5.68±0.03	3.48±0.03	247±2	0.388±0.006	8.48±0.03
1.255	6.04±0.03	3.72±0.09	282±7	0.384±0.015	8.74±0.08
1.266	6.46±0.02	3.92±0.04	320±4	0.396±0.007	8.97±0.04
1.254	6.36±0.02	3.98±0.07	317±6	0.375±0.011	9.00±0.06
1.253	6.44±0.04	4.06±0.09	328±7	0.371±0.014	9.08±0.08
1.257	6.73±0.03	4.37±0.06	370±5	0.351±0.010	9.39±0.05
1.258	7.34±0.04	4.71±0.07	435±6	0.358±0.010	9.77±0.06
1.258	7.64±0.05	4.93±0.07	473±7	0.355±0.010	10.00±0.06
1.266	7.84±0.03	5.09±0.14	504±14	0.350±0.018	10.17±0.12
1.253	7.98±0.08	5.09±0.12	509±12	0.363±0.017	10.18±0.10
1.255	8.09±0.05	5.18±0.11	526±11	0.360±0.014	10.28±0.09

Included on the graph is the measured sound speed¹⁹ of the liquid benzene at 22°C and local atmospheric pressure. In Fig. 5 the $P-V/V_0$ data are plotted along with the curves transformed from the fit of the U_s-U_p data. The initial density was 0.879 g/cc.

The U_s-U_p and $P-V/V_0$ plots indicate that a transition begins at about $U_s=5.80$ and $U_p=2.60$ km/sec, and a pressure of 133 kbar, and ends at about $U_s=6.30$, $U_p=3.50$, and a pressure of 194 kbar. It is possible that a transition occurs below 5 kbar since the lowest line segment extrapolates to a value on the U_s axis 14% higher than the measured sound speed. The $P-V/V_0$ data of Fig. 5 are represented by concave upward curves below 133 kbar and above 194 kbar, with a third curve fitted to the few points in between. If the upper Hugoniot curve is extrapolated to 133 kbar and the lower Hugoniot curve is used as a reference, the change in V/V_0 due to the transition is about 16%.

In many solids the occurrence of a normal instantaneous (less than 0.1 μ sec) transition is represented in the U_s-U_p plane by either a change in slope or by an interval of constant shock velocity. The latter case is usually accompanied by a double shock wave structure. The benzene U_s-U_p plot appears to contain a combination of both characteristics since the shock velocity increases very slowly with particle velocity over the small interval described in Eq. (8). However, the formation of a double shock structure is not expected because the Rayleigh line from the foot of the $P-V/V_0$ curve connects all points on the Hugoniot in a single shock process. This conclusion was verified by the performance of some double shock wave experiments as explained in Sec. II. Based on the above observations and a knowledge of other materials,^{18,20} benzene is believed to undergo an instantaneous transition for two reasons: (1) a sluggish (greater than 1 μ sec) transition is unlikely because a plot of the U_s-U_p data shows a

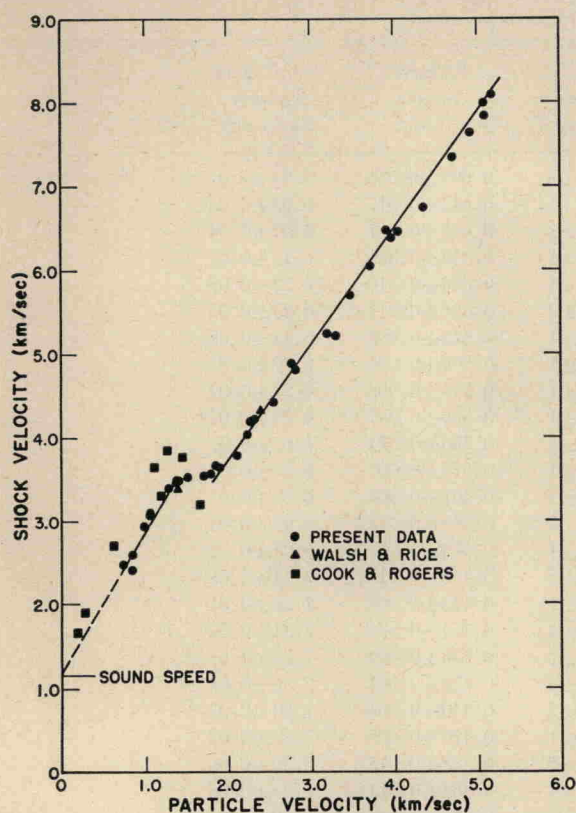


FIG. 6. Shock velocity-versus-particle velocity plot for carbon disulfide.

discontinuous change in slope and (2) there was negligible attenuation of the shock wave, indicating that a time dependent transition with a relaxation time of the order of the velocity measuring time does not occur. The absence of a double shock wave structure indicates the shock wave at the transition pressure is stable. Hence, the 133–194 kbar region may be a mixed phase region that occurs when a portion of the benzene transforms immediately to a new phase. The transformation is then complete at 194 kbar.

It is doubtful that the transition is due to freezing because the duration of the shock process is too short for rearrangement of the benzene molecules into a specific solid structure. Furthermore, pressure hinders rotation of the molecules. A temperature calculated at the beginning of the transition is 2300°K, based on the Mie-Grüneisen form¹⁵ for the equation of state. Under these extreme conditions of pressure and temperature, the molecular bonds are distorted sufficiently that polymerization can occur. Above 194 kbar the entire volume has undergone the transition and the Hugoniot curve is that of a more compact material. The temperature at this pressure is probably above 3500°K. A dynamic high-pressure study²¹ of some solid aromatic hydrocarbons (anthracene, pyrene, and phenanthrene) indicated that their behavior was similar to that of benzene. It was found that anthracene

transformed at about 180 kbar, phenanthrene at about 200 kbar, and pyrene at about 240 kbar. Hence, the transition pressures of the aromatic hydrocarbons and benzene are arranged according to the complexity of the individual molecules with benzene at the lowest and pyrene at the highest pressure. Perhaps benzene and the solid aromatic hydrocarbons undergo similar transformations.

The results of electrical conductivity experiments performed on benzene indicate no appreciable increase in conductivity up to pressures of 140 kbar.

The Hugoniot curve calculated by Salzman, Collings, and Pings²² using a Lennard-Jones and Devonshire intermolecular potential form appears to agree with the experimental Hugoniot curve up to about 130 kbar. The parameters they computed are $n=6.9$ (repulsion term), $r^*=5.92$ Å (position of the potential minimum), and $T^*=440^\circ\text{K}$ (temperature equivalent of the potential minimum).

C. Carbon Disulfide

The carbon disulfide Hugoniot data are presented numerically in Table II and graphically in Figs. 6 and 7. Distinctive features of the U_s-U_p plot of Fig. 6 are the representation of the data by two line segments separated by an interval of constant shock

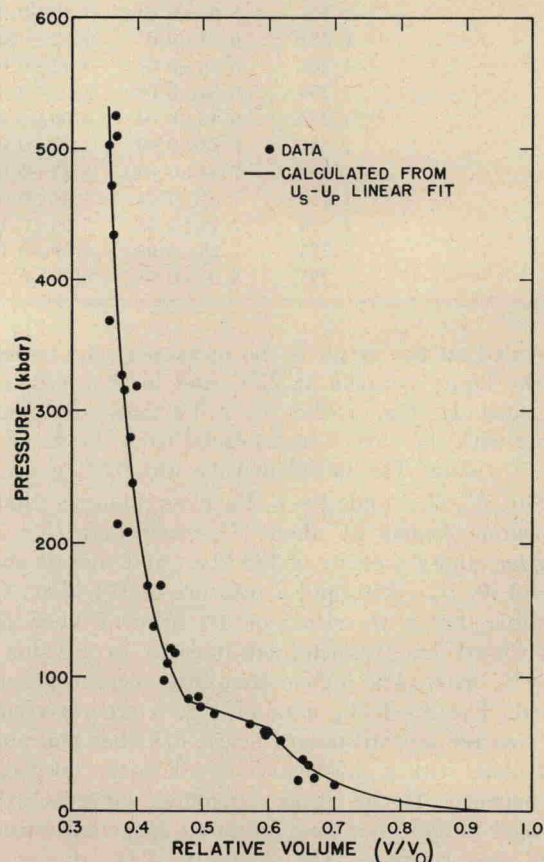


FIG. 7. Pressure-versus-relative volume plot for carbon disulfide.