

TABLE I. Shock wave data for benzene.

Initial density (g/cc)	Shock velocity (km/sec)	Particle velocity (km/sec)	Pressure (kbar)	Relative volume (V/V_0)	Dural shock velocity (km/sec)
0.877	2.78±0.01	0.77±0.09	19±2	0.722±0.031	5.93±0.07
0.869	2.72±0.01	0.89±0.04	21±1	0.671±0.016	6.02±0.03
0.870	2.96±0.02	0.89±0.05	23±1	0.700±0.016	6.02±0.04
0.870	3.31±0.01	1.05±0.03	30±1	0.684±0.009	6.16±0.02
0.875	3.44±0.01	1.12±0.03	34±1	0.676±0.009	6.22±0.03
0.879	3.47±0.01	1.12±0.04	34±1	0.676±0.011	6.23±0.03
0.880	3.85±0.01	1.36±0.03	46±1	0.647±0.008	6.43±0.02
0.866	3.89±0.00	1.45±0.02	49±1	0.627±0.006	6.50±0.02
0.885	4.05±0.01	1.45±0.03	52±1	0.642±0.007	6.52±0.02
0.877	4.05±0.01	1.48±0.03	53±1	0.635±0.006	6.54±0.02
0.881	4.09±0.01	1.59±0.09	57±3	0.612±0.021	6.62±0.07
0.869	4.38±0.01	1.77±0.03	67±1	0.597±0.006	6.78±0.02
0.869	4.52±0.01	1.85±0.01	73±1	0.591±0.003	6.86±0.01
0.885	4.79±0.02	1.90±0.05	81±2	0.603±0.010	6.92±0.04
0.871	4.77±0.02	1.94±0.02	81±1	0.593±0.004	6.95±0.02
0.870	5.00±0.02	2.16±0.10	94±4	0.567±0.019	7.14±0.08
0.870	5.28±0.01	2.29±0.02	105±1	0.567±0.003	7.26±0.01
0.875	5.46±0.01	2.33±0.02	111±1	0.575±0.004	7.31±0.02
0.880	5.52±0.02	2.37±0.04	115±2	0.570±0.007	7.35±0.03
0.868	5.71±0.01	2.61±0.03	129±2	0.542±0.005	7.56±0.03
0.887	6.00±0.03	2.86±0.03	152±2	0.523±0.006	7.80±0.03
0.871	5.93±0.02	2.92±0.02	151±1	0.507±0.004	7.83±0.02
0.876	6.17±0.02	3.34±0.08	180±4	0.458±0.013	8.20±0.06
0.870	6.22±0.04	3.44±0.06	186±3	0.446±0.010	8.29±0.05
0.870	6.43±0.03	3.66±0.03	205±2	0.430±0.005	8.48±0.03
0.874	6.82±0.06	3.92±0.09	234±6	0.425±0.015	8.74±0.08
0.881	7.23±0.01	4.15±0.04	264±3	0.426±0.006	8.97±0.04
0.872	7.16±0.03	4.20±0.07	262±5	0.413±0.011	9.00±0.06
0.871	7.25±0.03	4.29±0.09	271±6	0.409±0.013	9.08±0.08
0.875	7.66±0.05	4.61±0.06	309±4	0.398±0.009	9.39±0.05
0.876	8.24±0.05	4.99±0.07	360±5	0.395±0.009	9.77±0.06
0.876	8.61±0.04	5.21±0.07	393±6	0.395±0.009	10.00±0.06
0.881	8.91±0.07	5.38±0.14	422±12	0.396±0.017	10.17±0.12
0.871	8.82±0.08	5.42±0.12	416±10	0.386±0.015	10.18±0.10
0.874	8.97±0.06	5.51±0.11	432±9	0.386±0.013	10.28±0.09

locities in the liquids were determined from the times at which the shock front arrives at the coaxial electrical contactors¹⁶ located in the liquids at accurately measured distances from the 2024 dural plate-liquid interface. Other electrical contactors are placed in holes of accurately measured depths in the 2024 dural plate to determine the arrival time of the shock front at these levels. The shock velocity in each material was computed from a plot of the corresponding time-distance data.

The methods and techniques used for the liquid nitrogen experiments are similar. Figure 3 is a diagram of the shot assembly showing the double-walled construction for keeping the liquid nitrogen in a non-boiling state. A few seconds before detonating the explosive the styrofoam slab was removed remotely. This ensures that the cold apparatus is in contact with the warm explosive for a minimal period of time.

The observation of a transition occurring in benzene

and carbon disulfide and the character of their U_s-U_p plots led to some experiments to determine if a double shock wave structure^{17,18} was present. The apparatus consisted of a 2024 dural driver plate 0.64 cm thick backed by the appropriate explosive system, a liquid layer 1.27 or 2.54 cm thick, and a 0.64 cm thick 2024 dural cover plate. The free surface motion of the cover plate was determined from the times at which the electrical contactor pins positioned above the plate are shorted. If at the transition pressure the original shock wave is unstable two shock waves with different velocities are formed, one with the pressure of the transition and the other with the remainder of the pressure pulse. A separation in time occurs as the two shock waves traverse the liquid layer and cover plate. By doubling the thickness of the liquid the time separation is also doubled, neglecting attenuation. The free surface motion of the cover plate results from the two impulses received from the two shock waves. Care was

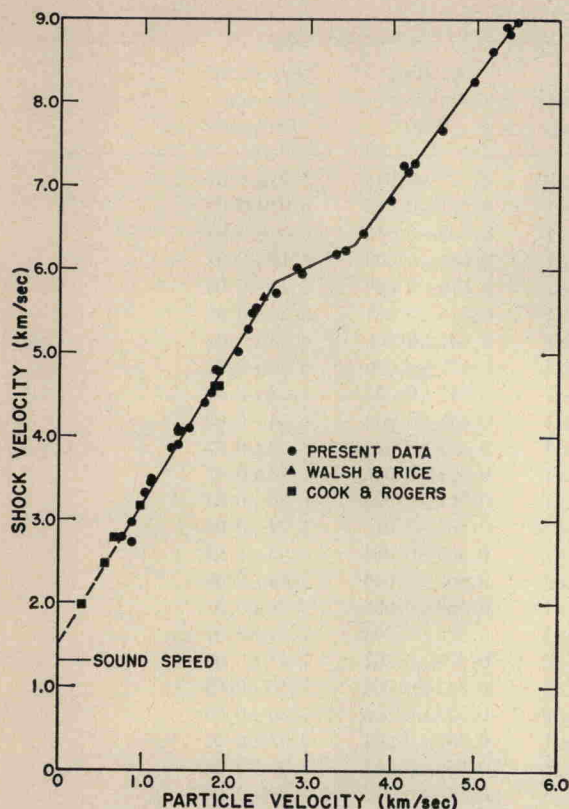


Fig. 4. Shock velocity-versus-particle velocity plot for benzene.

taken in designing the experiment to see that extraneous shock waves were not present.

III. EXPERIMENTAL RESULTS AND INTERPRETATION

A. General

The data for each liquid are presented as U_s-U_p and $P-V/V_0$ graphs. A linear relationship between U_s and U_p was observed for each of the liquids. The data were fit by a linear least-squares method to the equation

$$U_s = C + SU_p \quad (4)$$

The carbon tetrachloride and liquid nitrogen U_s-U_p data were also fit to a quadratic in U_p ,

$$U_s = C + SU_p + TU_p^2 \quad (5)$$

Benzene and carbon disulfide undergo a transition. There is less convincing evidence for the occurrence of a transition in carbon tetrachloride and liquid nitrogen.

For all materials the errors associated with the measured shock velocities represent the standard deviations computed from the linear least-squares fit of the time-distance data. These data were initially corrected for tilt in the shock wave. The standard deviations listed with the calculated values for pressure,

particle velocity, and relative volume were determined from the standard deviations computed for the measured shock velocities. The precision of the pin setback and hole depth measurements was 5μ and the precision in reading the pin signal times was 5 nsec. There was negligible attenuation of the shock wave over the distance established for measuring the shock velocity. The liquid density errors were about $\frac{1}{3}\%$ due mainly to a 2°C error in the temperature measurement.

The three organic liquids were reagent grade with a purity better than 99%. The liquid nitrogen was about 99% pure with the major impurity being oxygen.

B. Benzene

The Hugoniot data for benzene are listed in Table I. The U_s-U_p plot shown in Fig. 4 shows three line segments representing the data. An interesting feature of this graph is the short middle segment which has a relatively small slope. There is good agreement with the data of Walsh and Rice⁸ and Cook and Rogers.⁹ In the interval $2.70 \leq U_s \leq 5.83$ km/sec the fit of the U_s-U_p points is

$$U_s = 1.50 \pm 0.10 + (1.67 \pm 0.04) U_p \quad (6)$$

and from $6.26 \leq U_s \leq 9.00$ km/sec

$$U_s = 1.37 \pm 0.17 + (1.39 \pm 0.03) U_p \quad (7)$$

The short segment between $U_s = 5.83$ and 6.26 km/sec is fit by

$$U_s = 4.64 \pm 0.99 + (0.46 \pm 0.10) U_p \quad (8)$$

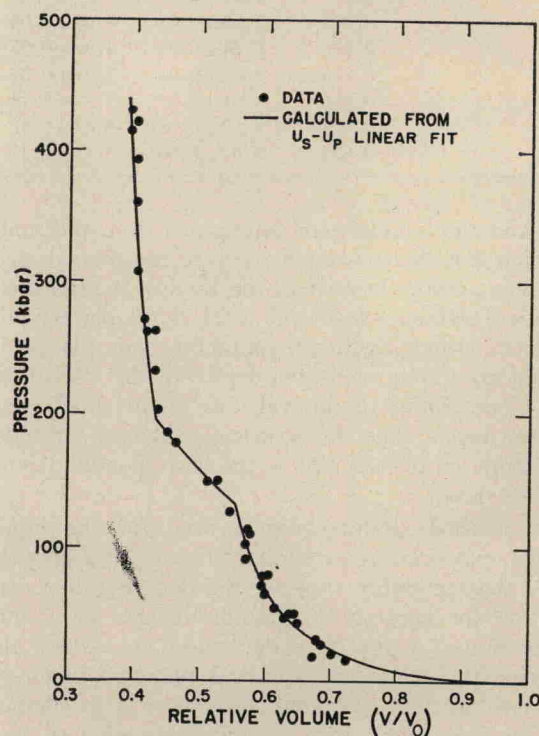


Fig. 5. Pressure-versus-relative volume plot for benzene.