phenomena being negligible in a detonation wave, the pressure at the detonation front should be approximately twice the Chapman–Jouguet pressure. Then as chemical reaction proceeds the pressure decays along the Rayleigh line to the Chapman–Jouguet value at the end of the reaction zone. For explosives of reaction zone length of only a few mm or less, such as composition B, the von Neumann spike might be difficult to detect. Previous experiments to determine the pressure profiles through reaction zones by means of the aluminum free surface velocity technique were devoted primarily to explosives of very short reaction zone length, i.e., composition B. This choice of explosive necessitated the use of very thin plates for which the free surface velocity measurements were in question.[17,18] Since there is no reason to believe that an overpressure would exist in a rapidly reacting explosive and not in a slowly reacting one, it would seem prudent to look for evidence of a spike in slowly reacting explosives. The blasting agents discussed by Bauer and Cook[14] represent a class of explosives known from their persistent nonideal behavior in large diameter charges to possess the longest reaction zones of the detonating type explosives, and according to any published theory, to possess reaction zone lengths sufficiently great that a spike could easily be detected by the aquarium technique. However, no evidence of the spike was observed in these or any of the nonideal explosives included in this investigation. The coarse TNT, especially $-4+6$ mesh TNT, also should have reaction zone lengths which are ample for easy detection of a spike by the aquarium technique. Moreover, conditions were ideal in this case for its detection, if it were present, owing to a nearly perfect impedance match between the explosive and water. Additionally nonideal behavior persists in some of these, e.g., $-4+6$ mesh, up to a 25-cm charge diameter. Figure 8 shows a trace for $-4+6$ mesh spherical TNT in a 25.3-cm-diam charge. One has no difficulty in such a case in obtaining accurately reproducible measurements owing to the relatively slow deceleration of the shock from such a large shock generator. With $-4+6$ mesh TNT in a 25.3-cm-diam charge, where the detonation velocity was finally in close agreement with the ideal value, and the impedance match was very good, the pressure of the incident wave corresponding to the initial velocity of the transmitted wave was found to be in close agreement with the Chapman–Jouguet value.

Published results of measured detonation pressures are not directly comparable to any presented here. Nevertheless an approximate comparison may be made with results for composition B presented by Deal based on two separate methods, namely the free surface velocity method[19] and another type of aquarium

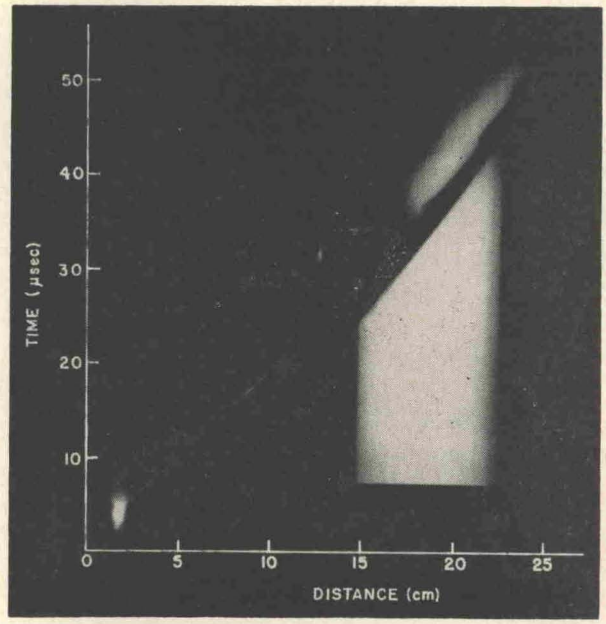

FIG. 8. Streak camera trace illustrating the aquarium technique for measurement of detonation pressure (explosive $-4+6$ mesh TNT at $d=25.3$ cm).

method.[20] Deal employed 65/35/1 composition B of density 1.714 g/cc and velocity 7.991 km/sec whereas the explosive used here was 60/40/1 composition B of $\rho_1=1.68$ g/cc and $D=7.80$ km/sec. Deal obtained 292.2 and 290.4 kbars by his free surface and aquarium methods, respectively, with a probable error in the aquarium method of only about 2.5 kbars. This is to be compared with the value 230 ± 10 kbars reported by Cook, Pack, and McEwan.[13] The two explosives are closely enough related that the results may be placed on a common basis by the approximation

$$p_2'/p_2'' \doteq \rho_1' D'^2/\rho_1'' D''^2, \tag{5}$$

which predicts that Deal's results should have been about 1.07 times higher than those measured here. After applying this correction to our results there remains a discrepancy of about 42 kbars which is 30 kbars outside the combined limits of experimental error.

Funk reinvestigated 60/40/1 composition B by the aquarium method using charges of larger diameter than in reference 13. The results are given in Table V and were 19.5 kbars higher than those obtained with the 2-in. charges used earlier. Moreover, the reproductibility was better due to the much lower rate of attenuation of the shock wave in water from the charges of nearly four times greater cross section. Still there remains a discrepancy of about 23 kbars between the results obtained by the aquarium method used here and those obtained by Deal. Since Funk's charges were large enough that nonideal effects should have been completely eliminated, apparently there remains a funda-

[17] R. E. Duff and E. Houston, *Second ONR Symposium on Detonation, Washington, D. C., February 9–11 (1955)*, p. 225.
[18] H. D. Mallory and S. J. Jacobs, *Second ONR Symposium on Detonation, Washington, D. C., February 9–11 (1955)*, p. 240.
[19] W. E. Deal, J. Chem. Phys. **27**, 796 (1957).
[20] W. E. Deal, Phys. Fluids **1**, 1523 (1958).

TABLE V. Detonation of composition B measured by Dr. A. G. Funk by IMER aquarium method.

Charge size	Density (g/cc)	p_2 (kilobars)	p_2 [corrected to 1.68 g/cc by approx. Eq. (5)]
3.94 in. (d)×12.13 in. (L)	1.70	256	249
3.89 in. (d)×15.98 in. (L)	1.69	255	251
3.63×3.32 in. (rectangular)×10.3 in (L)	1.67	243	247
3.62×3.24 in. (rectangular)×9.8 in. (L)	1.69	255	251
			249.5±1.5 kbars

mental discrepancy between the aquarium method employed here and that employed by Deal.

One of us has criticized the measurements of the "spike" in the detonation front by the use of very thin plates and the free surface velocity method.[16] This criticism, however, does not apply to Deal's measurements since he extrapolated to C–J conditions from free surface velocity measurements with adequately thick plates. Furthermore, the criticism should not be construed as a rejection of the Goranson theory of impedance mismatch which certainly has been adequately confirmed when applied to media of sufficient extent. More recent studies by Clay[21] seem to confirm, however, the suggested limitations of the shock wave reflection-transmission theory for very thin plates. Using microsecond framing camera sequences of the transmission-reflection characteristics of shock waves through brass plates of different thickness, Clay showed that ordinary laws of transmission-reflection at an interface apparently break down for thin plates of thickness below a certain critical value. Clay employed 3-in.^{2}×2-in. thick Plexiglas–x thick brass–3-in^2.×1-in. thick Plexiglas sandwiches shock loaded by 1-in.-diam ×2-in.-long 50/50 cast Pentolite. Intimate contact between the Plexiglas and the brass plate was achieved by fluidizing the surface of the Plexiglas with a thin film of ethylene dichloride. Clay observed that the ratio of the relative intensities of the transmitted to the reflected (shock) waves from the brass plates decreased from a very large (almost infinite) value at $x=0.05$ mm, through approximately unity at 0.3 mm, to a constant (normal) value at about 1.5 mm. Figure 9 shows four successive frames each of three framing camera sequences obtained by Clay at $x=0.05$ mm, $x=1.55$ mm and by Funk at $x=0.25$ mm. These results show that shock transmission-reflection conditions at an interface involve a type of "uncertainty principle" wherein ordinary shock wave theory for interactions at an interface breaks down if the dimension of the medium on either side of the interface in the direction normal to the wave front is below a certain critical value.

The discrepancy between the results of the aquarium method applied here and the free surface and aquarium methods employed by Deal may possibly be due to a fundamental difference between steady and nonsteady detonation waves. A steady detonation wave is not only one having a constant velocity but also one with a steady "detonation head" and a steady (spherical) wave front of constant radius of curvature.[16,22] In composition B the detonation head and wave front both require a run-up distance of about 3.5 to 4.0 charge

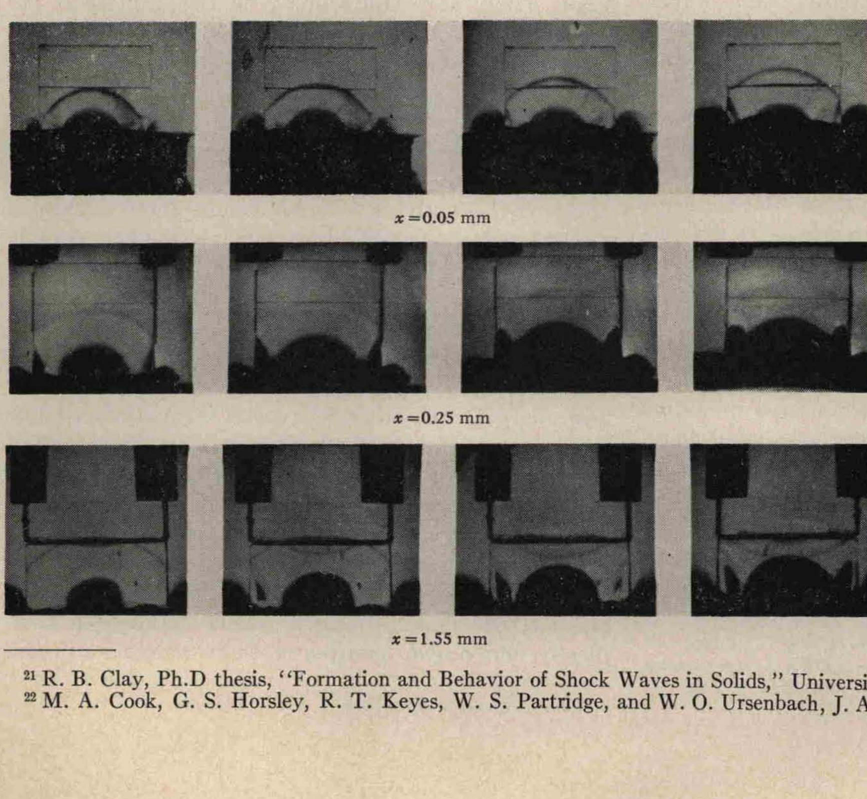

FIG. 9. Shock transmission and reflection by brass sandwiched between Plexiglas blocks showing effect of plate thickness on effective impedance of brass.

[21] R. B. Clay, Ph.D thesis, "Formation and Behavior of Shock Waves in Solids," University of Utah (June 1960).
[22] M. A. Cook, G. S. Horsley, R. T. Keyes, W. S. Partridge, and W. O. Ursenbach, J. Appl. Phys. **27**, 269 (1956).