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Reaction Sites in Condensed-Explosive Detonation Waves

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UNITED STATES
ATOMIC ENERGY COMMISSION
CONTRACT W-7405-ENG. 36

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Printed in the United States of America. Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U. S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy $3.00; Microfiche $0.65

Distributed: March 19, 1970

LA-4163-TR
UC-4, CHEMISTRY
TID-4500

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Reaction Sites in Condensed-Explosive Detonation Waves

by

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Source: Vzryvnoe Delo, Nauchn. Tekhn. Gorn. Obshchestvo, Sb. 63/20, 56 (1967).

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ABSTRACT

The heterogeneity of the detonation wave in gaseous and liquid explosives had been proved, but there was no way to show the space-time structure of the detonation wave front in powerful explosives. The authors photographed the face of exploding cartridges of nitromethane, a nitromethane and acetone mixture, and TNT. The photographs show heterogeneity of the detonation wave luminosity. Bright lines are attributed to the intense detonation reactions, and dark points to products that did not react at the instant of photographing. Heterogeneity was most clear in the nitromethane-acetone mixture. Discontinuity of bright sections, well expressed in TNT, was affected by the size distribution of the explosive granules. Luminosity of 0.5-mm-deep grooves on the charge face positively proved that bright lines of the detonation wave correspond to interstices between the explosive particles, and dark points correspond to unreacted particles.

Detonations close to the limiting conditions of propagation in gaseous mixtures have been studied in some detail, and the non-unidimensional structure of the detonation wave has been shown experimentally.[1-3]

The nature of the front's luminescence,[4] its scattering of light from outside sources,[5] and the detonation wave's translucence in a direction perpendicular to its propagation[6] attest to the non-unidimensional structure of the wave in certain liquid explosives also. In homogeneous solid explosives, one can expect a complete analogy with liquids, whereas in dispersed substances, the non-unidimensional nature of the detonation wave must be caused by the physical inhomogeneity itself.

Until now there has been no concrete evidence of the reaction sites in condensed explosives or of their relation to the shock wave. Existing experimental technology does not permit showing the space-time structure of a detonation wave front. Therefore, indirect methods that give information on the structure of the front are of interest.

We have obtained instantaneous photographs of the detonation wave in nitromethane, in a mixture of nitromethane and acetone (75/25 nitromethane/acetone), and in TNT of varying particle size. As a basis for our photographic method, let us examine the cause of the luminescence accompanying the dispersion of the detonation products.

Opinions on the cuase of the luminescence differ. Some authors explain it as the ionization of gases in the shock wave;[7] others link the intense luminescence in gases adjacent to the free surface of the detonating charge to chemical reaction in the high explosive.[8,9] The latter point of view is, apparently, more correct, as it is confirmed by test results. The luminescence in air of a shock wave created by a metal plate moving at $\sim$ 6 mm/μsec is far weaker than that of the detonation products themselves, which travel at $\sim$ 5 mm/μsec at a distance of 50 cm from the end of a nitromethane charge.

Figure 1 is a photoscan of the luminescence of detonation in a 75/25 nitromethane/acetone mixture. The luminescence at the wave front is nonuniform. We assume that it is the result of an intense reaction; it noticeably exceeds the luminescence of the final products.[3] Although some authors[10,11]

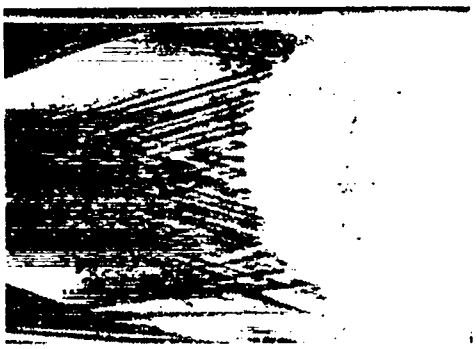

Fig. 1. Photoscan of detonation propagation in a 75/25 nitromethane/acetone mixture.

have established the presence of a process that leads to the absorption of light from outside sources before luminescence appears during the initiation of detonation by a shock wave, we assume that the nonluminescent parts of the front correspond to the nonreacting substance.

When the detonation arrives at the free surface, strong luminescence arises, primarily in regions aligned with the luminescent bands that correspond to the reaction sites. After the wave leaves the surface, the luminescence produces a great overexposure. Figure 2 is a photoscan of this process made with a normal-density negative. It does not show the detonation luminescence at all, whereas it clearly shows the striations in the luminescence, which was a solid bright region in Fig. 1.

From analysis of both experiments, we conclude that the structure of the luminescence during expansion of the detonation products in air is similar to that of the front of a detonation wave propagating through a charge. The luminescence of the detonation front itself can be captured only on high-sensitivity film whose low resolution does not permit showing many details of the phenomenon.

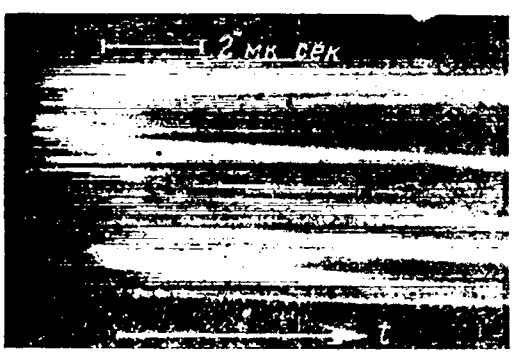

Fig. 2. Photoscan of detonation-product emergence from the free surface in a 75/25 nitromethane/acetone mixture.

The scheme for photographing the end of the detonating charge is shown in Fig. 3. Liquid explosives were contained in a 150-mm-high by 54-mm-i.d. metal cylinder. The TNT charges, in a 15-mm-high by 69-mm-i.d. metal jacket, ranged from 0.9 to 1.0 g/cm^3 in density. A pigment (not more than 0.5 g/liter) was added to the liquid explosives so that the luminescence of the propagating detonation was not recorded on the stationary film. A low-sensitivity, high-resolution film, "Mikrat-300," was used. The end of the charge was closed with a 20-mm-thick glass cover to capture the luminescence of the detonation products. The glass remains transparent until the shock wave arrives at the free surface, when it ceases to transmit light;[12] thus, the glass serves as an optical shutter.

Normal exposure conditions were ensured by a 0- to 0.75-mm air gap between the glass and the end of the charge. The luminescence in this gap gave a fairly long-lived picture of the reaction-site contours in the front of the detonation wave at the moment of its arrival at the surface, and because of the short ($\sim$ 4-μsec) exposure, we were able to obtain instantaneous photographs of the front (Fig. 4).

Figures 4 a and b show nitromethane and the 75/25 nitromethane/acetone mixture, respectively. This photographic method does not permit determining the shape of the reaction sites in pure nitromethane. The presence of dark regions bordered by bright lines is characteristic of the 75/25

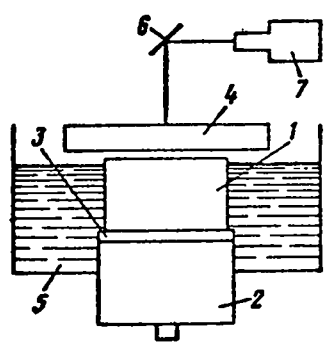

Fig. 3. Test setup. 1. Explosive charge. 2. Initiating charge. 3. Barrier of inert material. 4. K-8 optical glass. 5. Water-filled container. 6. Mirror. 7. Camera with open shutter.

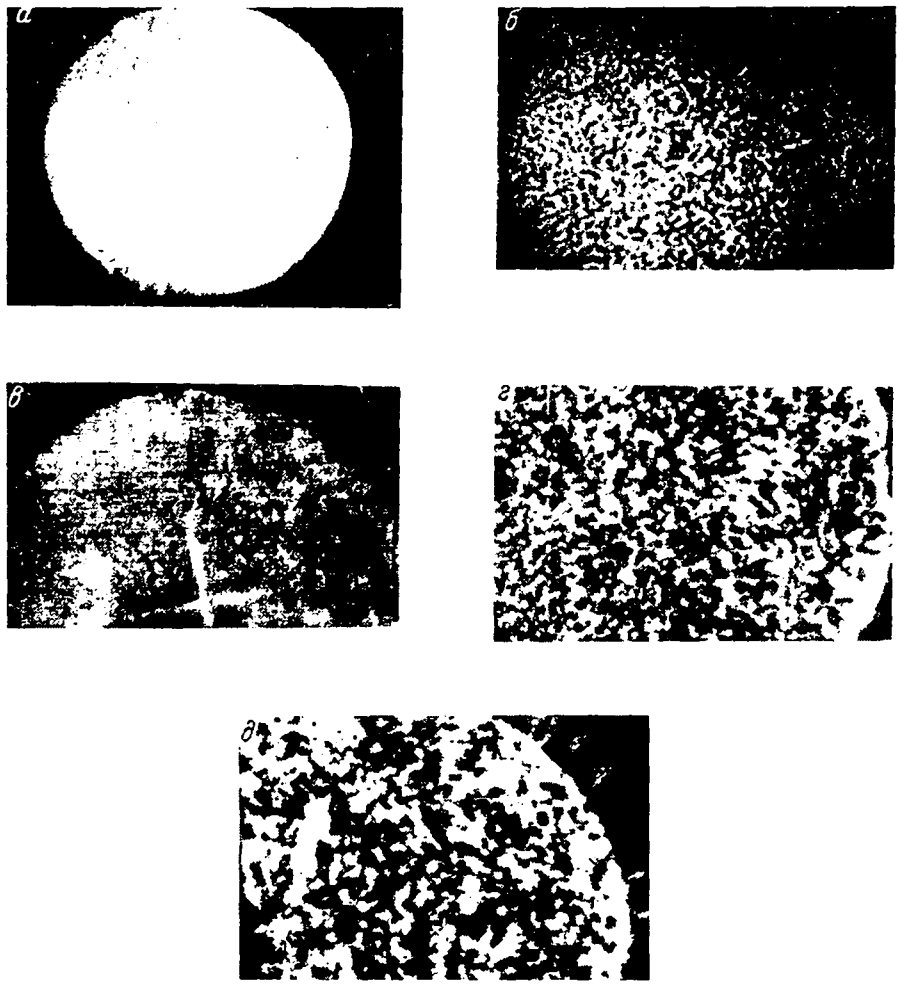

Fig. 4. Instantaneous photographs of the front of a detonation wave.
a. Nitromethane, air-gap thickness, ζ, 0.2 mm.
b. 75/25 nitromethane/acetone mixture, ζ = 0.5 mm.
c. TNT, particle size, Δ, 0.3 mm, ζ = 0.2 mm.
d. TNT, Δ = 0.8 mm, ζ = 0.
e. TNT, Δ = 1.5 mm, ζ = 0.

nitromethane/acetone mixture. Isolated bright spots are seen significantly less often.

We could not trace any regularities in inhomogeneous TNT charges, but the discontinuous nature of the luminescence is clearly evident and is determined by the size of the explosive particles (Figs. 4c, d, and e).

We punched a 0.5-mm-deep cross on the end of one of the charges to simulate the air gaps between the particles. The luminescence of this cross confirms that the source of the luminescence is the gaps between the particles in inhomogeneous charges. The dark areas in the photographs correspond to unreacted particles of explosive.

How does our test setup differ from the ideal, which would not use the glass and would employ a camera with a high-speed shutter? The unreacted explosive and detonation products entering the air gap are subjected to an additional compression by impact on the glass. The discontinuity of the luminescence indicates that the explosive compressed in the reflected shock wave usually cannot react during the short ($\sim$ 4 μsec) exposure time. This can be judged on the basis of the results of tests involving the collision of two 70-kbar-amplitude shock waves in nitromethane, in which the reaction occurs with enormous (greater than 20 μsec) delays. However, the possibility of a chemical conversion, but without strong luminescence, is not excluded.

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