

I thank Mr. N. L. Paddock for sending me the typescript of a forthcoming paper.

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Heat Pulses at Initiation of Liquid Explosives

THE hydrodynamic theory of detonation has proved to be very fruitful for the discussion of steady detonation. According to the theory an intense shock wave is a prerequisite for the accomplishment of the chemical reaction during the short space of time that is available. The theory does not, however, explain how the shock wave is generated at initiation.

Cook *et al.*¹ assume that 'heat pulses' in some cases play an important part in the initiation process. In the present investigation the possibility of a heat pulse which propagates at a great speed without being directly associated with a shock front is discussed. It is preliminarily assumed that the temperature in a layer of nitroglycerine suddenly rises to such a height that the chemical reaction is completed by a few impacts. Owing to the relaxation of the rotational and vibrational energy the released explosion energy will be concentrated on the translational degrees of freedom²⁻⁴ of the newly formed molecules. After some tens of collisions the molecules have approximately acquired the Maxwellian distribution of velocities and this corresponds to a 'translational temperature' T^x , which is considerably higher than the equilibrium values. The transfer of the energy to other degrees of freedom proceeds comparatively slowly. The number of collisions required for the development of rotational energy is about 10^3 and of vibrational energy about 10^5 . For T^x :

$$E_e/n = 3RT^x/2 \quad (1)$$

applies. E_e is the explosion energy, n the number of molecules in the detonation gas per molecule of explosive and R the gas constant. For nitroglycerine⁵ $E_e = 340,000$ kcal./kmol., $n = 7.25$ and $T^x = 15,800^\circ$ K. The fraction of impacts which leads to decomposition is:

$$q = e^{-E_a/RT^x} \quad (2)$$

Insertion of Roginsky's⁶ value for the activating energy, $E_a = 48,000$ kcal./kmol., gives $q = 0.22$. According to this $n_s = 1/q = 4.5$ impacts are sufficient for the decomposition of the nitroglycerine molecule $C_3H_5(ONO_2)_3$, and due to the high density the reorganization of the atoms to CO_2 , H_2O , N_2 and O_2 is in all probability a very rapid process. The result goes to prove that it is possible for a decomposition

process of this kind to continue once it has got well away.

The mean velocity of the newly formed molecules can be obtained from the relation:

$$M\bar{v}^2/2 = E_e/n$$

in which

$$\bar{v} = 0.92\sqrt{v^2}$$

This gives the following velocities in metres per second:

$$3 CO_2 : \bar{v}_1 = 2,750; 2.5 H_2O : \bar{v}_2 = 4,300; \\ 1.5 N_2 : \bar{v}_3 = 3,440; 0.25 O_2 : \bar{v}_4 = 3,220.$$

The figure before the gas indicates the number of molecules per nitroglycerine molecule. The arithmetical mean value for all molecules is $\bar{v} = 3,440$ m./s. This high molecular velocity corresponds to a high velocity for the propagation of disturbances.

For liquid nitrogen at -199° C. the ratio between the velocity of sound and the molecular mean velocity is approximately $m = 4$, and according to Rice and Walsh's^{7,8} results for water the ratio between the shock velocity and the molecular velocity lies between $m = 4.2$ at 8 kbar. and 50° C. and $m = 5.6$ at 250 kbar. and $1,670^\circ$ C. At atmospheric pressure and room temperature the velocity of sound in water is only 2.5 times the molecular velocity, but this may be due to molecular association which makes the estimated molecular velocity too high. For organic liquids the ratio between sound and molecular velocity at atmospheric pressure and room temperature is, as a rule, between 4 and 6.

According to Campbell, Davis and Travis⁹ we have the following process in transmission of detonation from a donor charge through an inert layer to a receptor charge of a liquid explosive. Behind the front of the incoming shock wave the receptor is heated by shock wave compression. If the temperature is above a certain level an accelerated rise in temperature by self heating is started. The maximum of this rise lies close to the impact surface similarly to what Selberg and Johansson¹⁰ have shown for the environment of a wire suddenly heated. There should probably be prerequisites here for a 'heat pulse'. Campbell, Davis and Travis observed a frontal velocity of 10,400 m./s. when the particle velocity was 1,600 m./s. $\bar{v} = 3,440$ m./s. and $m = 5$ gives a velocity of disturbance in nitroglycerine of 17,200 m./s. In calculating the propagation velocity of the heat pulse the time for dissociation of the explosive molecules must be taken into consideration. Since a self-heating process is in progress in the receptor charge it seems reasonable to assume that $n_s < 4.5$.

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