EXPERIMENTAL INVESTIGATION OF EXPANSION FOLLOWING THE PASSAGE OF A POWERFUL SHOCK WAVE

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When a shock wave passes through a body and reaches the free surface, the material begins to expand. If the shock wave is a powerful one and the internal energy of the heated material exceeds by many times the binding energy of the atoms, the material is vaporized and behaves like a gas. The theory of this expansion has been examined by Zel'dovich and Raizer [1, 2]. However, these authors assume that it is not yet possible to obtain a final solution of the problem for lack of a theory satisfactorily describing the thermodynamic functions of matter in the region of densities somewhat less than normal for the solid state. The phase transformation kinetics may also play an important part in this expansion, but these questions have received little theoretical attention, and, as far as the author is aware, have hardly been studied at all experimentally.

"Instantaneous" heating by laser radiation has recently been used to determine the thermodynamic properties of materials at densities close to solid-state density and to study their expansion [3–6].

In order to observe the processes of expansion following instantaneous heating we conducted experiments on the expansion of a paraffin plug after passage of a plane shock at a velocity of 33 km/sec.* After the shock wave reached the free surface of the plug, the paraffin expanded into a cylindrical channel of the same diameter as the plug filled by air at various pressures (760, 85, 0.1 mm Hg). In these experiments we recorded the velocity of the shock wave in the plug and the velocity in the air filling the tube by means of an SFR-2M high-speed photorecorder.†

The results of the experiments are presented in Fig. 1, which shows the expansion velocity of the paraffin as a function of the pressure in it (points 1, 2, 3, and 4). The mass velocity of the expanding paraffin and pressure acting on it, equal to the pressure in the air shock propagating in front of the expanding paraffin, were determined from the data of [7]. Point 1 was plotted on the basis of the experimentally determined velocity of the shock wave in the paraffin plug. The equation of state used for the paraffin was similar to that employed for the detonation products of condensed explosives $p = A\rho^3$. The curve of isentropic expansion of the paraffin after the shock wave reached its surface was also calculated on the basis of this equation. The calculations were analogous to those made in [8] for the expansion of the detonation products of condensed explosives. It is clear from the figure that the experimental point obtained for the expansion of paraffin into air under normal conditions (point 2) lies very close to the calculated curve ($\gamma = 3$). The density of the paraffin for this point, calculated from the curve with exponent 3, is equal to ~ 0.3 g/cm^3. The position of points 3 and 4 at a considerable distance from the curve with exponent 3 shows that expansion to lower pressures proceeds at a smaller value of the exponent. A similar change in the value of the exponent is also observed in connection with the expansion of the explosion products of condensed explosives. The calculations of Jones and Miller [9] show that a change in the exponent from 3 to 1.27 may be assumed to occur on a rather narrow interval of densities and pressures ($\rho \sim 0.3$ g/cm^3). Assuming that in the expansion of paraffin the change in the exponent takes place in a similar way, we attempted by trial and error (for points 3 and 4) to calculate the subsequent expansion curve with exponent 1.3. As our starting data we took the parameters between points 2 and 3 and the requirement that the curve pass close to point 4 (curve $\gamma = 1.3$).

On the basis of these experiments it may be concluded that after the passage of a shock wave at a velocity of 33 km/sec paraffin expands with a variable adiabatic exponent. Up to a certain counterpressure (expansion into air under normal conditions) the exponent is close to 3 and the density of the expanding paraffin remains fairly high.

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*The pressure in the shock wave was $\sim 5 \cdot 10^6$ kg/cm^2 and exceeded the value $\rho c_0^2 = 4 \cdot 10^4$ kg/cm^2 for paraffin by two orders, which is ten times more than enough for the total evaporation of the paraffin [4].

†The motion of the shock wave in the plug was recorded from the end face with the axis of the plug and the axis of the instrument forming an angle of 15–20°. At the recorded velocities the shock wave in the paraffin is luminescent and visible through the supervening layers. The velocity 33 km/sec is the arithmetic mean of the results of five independent experiments. In this case the standard deviation $\sigma = 0.85$ km/sec. As it traveled through the plug, the shock wave maintained a velocity constant within the limits of error of the measurements.

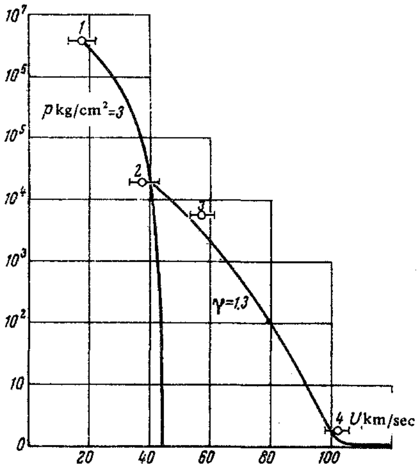

Fig. 1

In [3−6] the adiabatic exponent was assumed constant, which may have had an important influence on the accuracy of the results.

The observed law of expansion of paraffin after instantaneous heating in a powerful shock wave should evidently also apply to the expansion of other substances.

Thus, the effect has been used to obtain a compact mass of tungsten particles with a velocity of 24 km/sec and density ~ 1 g/cm^3, whose action on targets is described in [10]. In the case of expansion into a vacuum (10^{-2} mm Hg) the tungsten particles acquire a velocity of 68 km/sec.

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