

# ON THE QUESTION OF THE IGNITION OF AN ADIABATICALLY HEATED GAS MIXTURE

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**Abstract**

**Full Text**

**PHYSICAL CHEMISTRY**

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**ON THE QUESTION OF THE IGNITION OF  
AN ADIABATICALLY HEATED GAS MIX-  
TURE**

*(Presented by Academician V. N. Kondrat'ev, 11 VI 1958)*

In works <sup>(1-4)</sup> devoted to the study of the ignition of homogeneous gas mixtures under conditions of rapid adiabatic heating, the following features of the phenomenon were noted: the existence of a finite induction period and the occurrence of ignition centers at the initial stage of the process. However, it was not possible to carry out a detailed study of the process of the appearance and development of ignition centers because the resolving power of the recording apparatus was insufficiently high.

In the present work, the appearance and development of an exothermic reaction in a homogeneous gaseous medium adiabatically heated to temperatures of 600—1400° at pressures of 1—3 atm is investigated. The experiments were carried out in a shock tube <sup>(5)</sup>. The cross section of the internal channel was 40 × 40 mm, the length of the low-pressure chamber was 2 m, and the length of the high-pressure chamber was 0.7 m. In the mixture under investigation, located in the low-pressure chamber, a shock wave *S* was produced; it propagated along the channel and was normally reflected from the end wall of the chamber. The intensity of the wave was chosen in such a way that the temperature  $T_2$  behind the front of the reflected shock wave *R* lay within the range under investigation. In this case the value of the temperature  $T_1$  behind the wave *S* did not exceed 500°. The side walls of the section in which normal reflection of the wave *S* from the end wall of the chamber occurred were made of plane-parallel plates of optical glass. Density changes in this section, whose length was 158 mm, were recorded by the Schlieren method with the aid of an IAB-451 apparatus, both by high-speed frame photography (Fig. 1) and by the sweep method (Fig. 2). Pulse piezoelectric pressure transducers were mounted in the upper wall and in the end wall of the chamber <sup>(6)</sup>.

The study of ignition processes was carried out in oxygen-hydrogen mixtures. Schlieren photographs of the gas state under investigation, as well as the pressure recorded on the chamber walls, show that the gas behind the wave *R* experiences small disturbances of pressure and density. The amplitude of the pressure oscillation does not exceed 5% of the absolute value. The density oscillations do not exceed 0.5% of the absolute value. It should be noted, however, that the

Fig. 3. Dependence of the ignition delay of the  $H_2 + O_2$  mixture on temperature

Figure 1: Fig. 3. Dependence of the ignition delay of the  $H_2 + O_2$  mixture on temperature

indicated density and pressure disturbances behind the reflected wave  $R$  are also observed in inert gases—in air and nitrogen. Thus, the nature of these disturbances is not connected with the specific properties of the chemically reacting gas mixture.

Using the values of the pressure  $P_0$  and temperature  $T_0$  ahead of the wave  $S$  and the velocity of its motion, determined from Schlieren photographs, the pressure  $P_2$  and temperature  $T_2$  of the mixture under investigation in the state behind the wave  $R$  are calculated from the known formulas of gas dynamics. The calculated pressure value agrees with the experimentally measured one. On this basis, the calculated value of the temperature  $T_2$  was used in describing the process. The experimentally observed disturbances of optical density

in the region under study do not exceed 0.5%; the temperature fluctuations corresponding to these changes do not exceed  $10^\circ$ . Let us note that, owing to the interaction of the reflected shock front  $R$  with the boundary layer of the flow (<sup>7</sup>) following the wave  $S$ , a curvature of the surface of the front  $R$  occurs, which leads to an apparent broadening of the front in the schlieren photographs (Figs. 1, 2).

The ignition process in an adiabatically heated mixture proceeds as follows. The visible reaction, accompanied by intense emission of light and a sharp change in the thermodynamic parameters of the gas mixture, initially arises at one or several points of the volume under investigation—the centers of reaction. Initially occupying a small volume near the reaction center, the region of gas in which the visible reaction occurs—the ignition kernel—increases with time.

**Fig. 3.** Dependence of the ignition delay of the  $H_2 + O_2$  mixture on temperature

The value of the velocity of motion of the front of the ignition kernel at a mixture temperature of  $900^\circ$  is 180–200 m/sec. After several ignition kernels have coalesced in the investigated volume of the gas mixture, shock discontinuities are observed to arise in the region thereby formed. The velocity of motion of the front of the newly formed region increases to a value of the order of 2000 m/sec. In Fig. 1 the reaction center is recorded in the tenth frame; in the next frame the ignition region is registered. The velocity of motion of its front is 1900 m/sec. A quantitative study of the process described above was carried out with the aid of schlieren photographs by the sweep method. A typical photograph of the process obtained by this method is shown in Fig. 2. The absolute error in determining the velocity of motion of the waves  $S$ ,  $R$ , and of detonation and normal combustion does not exceed 20 m/sec; the error in determining the instant of occurrence of the reaction center does not exceed  $\pm 2 \mu\text{sec}$ .

The probability of occurrence of a reaction center at a fixed point of the volume under investigation depends on the time intervals  $\tau_1$  and  $\tau_2$ , during which the selected part of the gas volume was at temperatures  $T_1$  and  $T_2$ , respectively. Heating of the gas from temperature  $T_0$  to temperature  $T_2$  is effected by the wave  $S$ , and heating from  $T_1$  to  $T_2$  by the wave  $R$ . The ignition delay of a mixture instantaneously heated from temperature  $T_0$  to temperature  $T$  is measured by the time interval  $\tau$  from the moment of heating of the mixture to the moment of appearance in it of the first reaction center. The time interval  $\tau_2(x)$  between the instant of instantaneous heating from  $T_1$  to  $T_2$  of a layer of mixture located at a distance  $x$  from the end of the chamber and the instant of occurrence in it of a reaction center decreases with increasing  $x$ , i.e., with increasing residence time of the considered volume of mixture at temperature  $T_1$ . From the values of  $\tau_2(x)$ , determined experimentally from schlieren photographs of the process, the value of  $\tau$ , equal to  $\tau_2(0)$ , was determined. The experimental values of  $\lg 1/\tau$  as a function of the temperature  $T$  are given in Fig. 3. The changes in  $\lg 1/\tau$  as a function of pressure in the range from 1 to 3 atm are small in comparison with its absolute value. The experimentally determined values of the ignition-delay period agree satisfactorily with the induction period calculated according to the chain theory<sup>(8,9)</sup>.

It appears to us that the ignition process under the conditions described above develops in the following way. In the volume of gas, after its heating, the concentration of active intermediate products increases<sup>(7)</sup>. After the expiration of the induction period, at certain points of the volume

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[Figure 1]

**Fig. 1.** Schlieren photograph of the ignition process. Filming rate 35,000 frames per second.

**i. c.** —ignition center

[Figure 2]

**Fig. 2.** Schlieren photograph of the ignition process by the sweep method. **a** —trace of wave  $R$ , **b** —trace of wave  $S$

To the article by A. S. Shevlyakov, V. S. Etlis, K. S. Minsker, L. M. Degtyareva, G. T. Fedoseeva, and M. M. Kucherenko, p. 1077

[Figure 4]

**Fig. 4.** X-ray diffraction patterns of isotactic (**a**) and amorphous (**b**) polystyrene samples

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conditions are created that lead to avalanche acceleration of the reaction in this part of the volume—a reaction center is formed. The further development of the reaction from the center to the adjacent layers of the mixture is determined by

the processes of normal propagation of the flame front. Because, in an adiabatically heated mixture, a system of centers always arises, the ignition of some volume elements occurs under conditions in which the latter are surrounded on all sides by combustion fronts. This leads to the formation of local explosions, accompanied by the appearance in the combustion products of shock discontinuities observed experimentally. The shock discontinuities, passing into the region of unburned gas, form fronts of detonative combustion.

In conclusion, the authors consider it a pleasant duty to express their deep gratitude to A. S. Predvoditelev, E. V. Stupochenko, and T. V. Bazhenova for their constant attention to the work and valuable comments.

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