ANALYSIS OF THE PROCESS OF RAISING THE TEMPERATURE IN THE SPARK CHANNEL AT A DISCHARGE IN GAS

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Analysis of the process of raising the temperature in the spark channel at a discharge in gas is performed. The quantitative evaluation was made in main for the air. The effect of steadying a thermodynamic equilibrium in gas, as well as the influence of power discharge parameters on the process of temperature increasing was analyzed. The quantitative evaluation of time parameters of the processes of rotary, oscillatory relaxation, dissociation and ionization has allowed to reveal the influence of each of them on temperature increasing in the spark channel. The problems arising in the course of practical realization of a spark discharge which influence on the process of temperature raising are detected, and the ways for their solution are determined. The results obtained can be put in a basis of developing the methods to design devices for intensive increase of temperatures in gas media using the electrical discharge, as well as for analysis of a dependence of shock wave intensity on dynamic parameters of the electrical discharge.
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Dynamics of a shock wave development is determined by a relation between the energy release rate in the spark channel and the rate of volume energy density decreasing as a result of shock wave propagation. If in the center of a spark discharge the increase of the temperature and pressure takes place, the intensity of the shock wave will raise. There is a problem of effective energy release, connected with pumping a translational energy. In the center of a discharge after shock wave formation the area of gas with a high temperature, but with a low density is formed. Let's assume that the discharge will go in the high- temperature field with the appropriate high degree of ionization. Then, because of the low density in the zone of discharge, the electron-molecule collision frequency will decrease with simultaneous increase of the length of free-path electrons, and consequently, with increase of their energy. These results in changing the range of effective cross-sections of gas molecule excitation in the field of intensive pumping of gas molecules with an oscillatory energy and electronic excitation (see Fig. 1, 2). In Fig. 1 the comparison of cross-sections of various processes in electron - N_2 molecule collision is given. At an electron energy of about 10eV the process of molecule dissociation by electron impact begins (see Fig. 2) [2].

Proceeding from above-stated, it is possible to make a conclusion, that the major pumping of gas molecules with the translational energy, immediately through electron-molecular interaction, is carried out before the moment of shock wave formation. It explains the fact of insignificant growth of the shock wave intensity with increasing the volume power of energy release. The main influence on further temperature increasing is exerted by the process of steadying the thermodynamic equilibrium in gas.

Experimentally it has been established, that the rotational energy of molecules reaches a classical equilibrium value kT (of two atomic molecules) after ten gas-kinetic impacts (see Tab. 2) [2]. From here, this type of energy will be a source of translational temperature increasing in the epicentre of a wave, as the rate of rotational energy - into -translation energy relaxation exceeds the rate of the energy volume density decrease as a result of shock wave development.
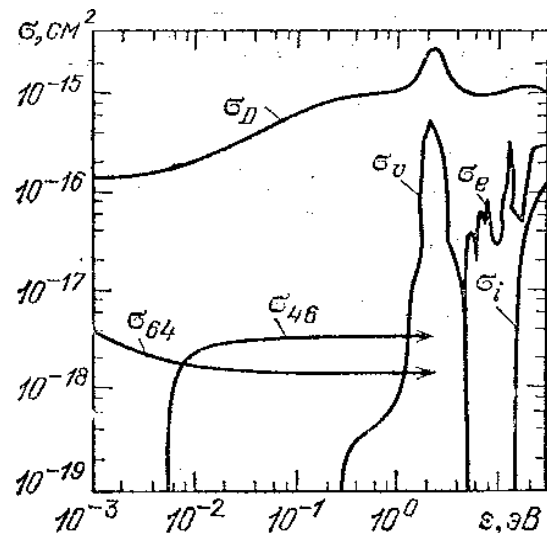

Fig. 1. Comparison of cross-sections of various processes in electron - N_2 molecule collisions: σ_D - elastic transport, σ_{46} and σ_{64} – rotational excitation at a level $j = 4$ to a level $j = 6$ and deactivation ($T = 77$ K, theory); σ_v - summarized cross-section of excitation of 8 oscillation level; σ_e - summarized excitation of electron levels with energies from 5 to 14 eV, σ_i - ionization.

Absolutely other picture takes a place in the case of steadying the thermodynamic equilibrium τ_{oscil} by the oscillation energy. The time of the oscillatory relaxation is determined by the formula:

$$\tau_{\text{кол}} = Z_{10}/Z , \qquad (1)$$

where Z_{10} is the most probable number of collisions preceding the oscillatory relaxation of molecules, Z is the total number of collisions per one second in a unit of volume.

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ВОПРОСЫ АТОМНОЙ НАУКИ И ТЕХНИКИ. 2001. №5.
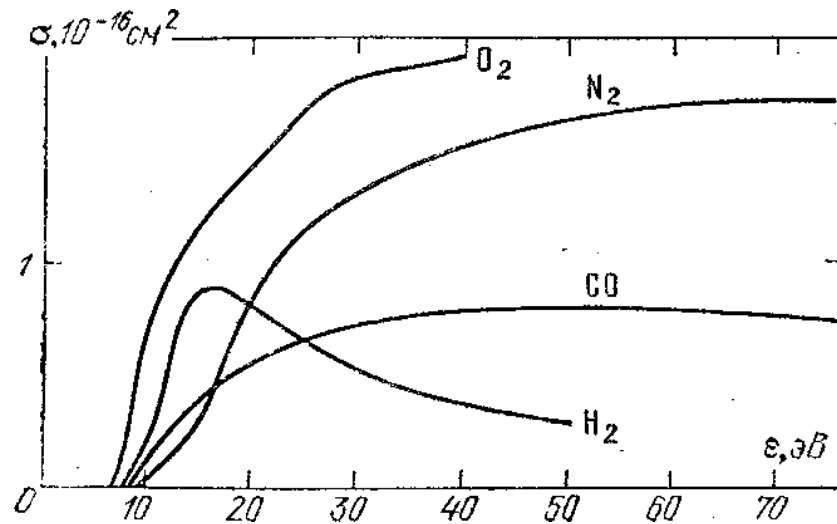*Серия:* Ядерно-физические исследования (39), с. 48-50.

Fig. 2. Full cross-sections of molecule dissociation by electron impact through excitation of various electronic conditions.

Table 1. A rotational relaxation of molecules

Molecule	Temperature, K	Time of a relaxation at atmospheric pressure, s	Number of collisions	Method
H_2	300	$2.1 \cdot 10^{-8}$	300	Ultrasound
H_2	300	$2.1 \cdot 10^{-8}$	300	Shock wave
D_2	288	$1.5 \cdot 10^{-8}$	160	Ultrasound
N_2	300	$1.2 \cdot 10^{-9}$	9	Ultrasound
N_2	300		20	Shock wave
O_2	314	$2.2 \cdot 10^{-9}$	12	Ultrasound
O_2	300		20	Shock wave
NH_3	293	$8.1 \cdot 10^{-10}$	10	Ultrasound
CO_2	305	$2.3 \cdot 10^{-9}$	10	Ultrasound

Table 2. An oscillatory relaxation in oxygen by Blackman measurements. Theoretical values by Schwarz and Hertzfeld

T, K	P_{10}, (Experiment)	P_{10}, (Theory)	Number of collisions Z (Experiment)	τ in s is reduced to a densities $n = 2.67 \cdot 10^{27}\,\text{m}^{-3}$
Oxygen				
288	$4 \cdot 10^{-8}$		$2.5 \cdot 10^{7}$	
900	$1.1 \cdot 10^{-5}$	$3 \cdot 10^{-6}$	$1 \cdot 10^{5}$	$96 \cdot 10^{-7}$
1200	$2.4 \cdot 10^{-5}$	$1.3 \cdot 10^{-5}$	$5 \cdot 10^{4}$	$41 \cdot 10^{-7}$
1800	$9.8 \cdot 10^{-5}$	$8.6 \cdot 10^{-5}$	$1.4 \cdot 10^{4}$	$9.5 \cdot 10^{-7}$
2400	$3.7 \cdot 10^{-4}$	$5.5 \cdot 10^{-4}$	$4.5 \cdot 10^{3}$	$2.7 \cdot 10^{-7}$
3000	$1.2 \cdot 10^{-3}$	$1.5 \cdot 10^{-3}$	$1.6 \cdot 10^{3}$	$0.83 \cdot 10^{-7}$

This relation is applicable in a case, when under condition with the first level of oscillatory excitation the small number of molecules is and there is no possibility of inverse processes. If there are also the more high levels of oscillatory excitation, then they pass to the Boltzman distribution as a result of cascade passages. The time of steadying such an equilibrium has an order of time of a translational relaxation.

In Table 2 the following labels are accepted: P_{10} - probability of molecule passage from the condition with an exited first oscillatory level into zero one at a single act of impact, Z - number of molecule impacts preceding oscillatory relaxation, τ – time of oscillatory relaxation.

Experimentally it is established that the probable number of molecule collisions in the air, preceding the oscillatory relaxation, as a minimum by two order of magnitude is higher than the rotary one [2]. The careful research of the relaxation in oxygen and nitrogen with the help of a shock tube was carried out by Blackman. His results are presented in Table 2 [2]. Calculations with using the data of Table 3 and taking into account the rate of energy volume density decreasing because of shock wave development, show that in high- current discharges in the spark channel molecules are at high levels of oscillatory energy excitation. Therefore there are not created conditions for intensive oscillatory relaxation in high- current discharges. Hence, the oscillatory relaxation rate is less than the rate of the energy volume density decreasing due to shock wave develop-

ment. As a result, this process has not significant influence on the shock wave intensity, during the discharge in the open space.

Table 3. The calculated parameters of excitation levels for various gases

Parameter	N_2	O_2	H_2	N_2^+	O_2^+
$\hbar \cdot \varpi_e$, eV	0.29	0.19	0.54	0.27	0.23
$\hbar^2 / 2 \cdot I_M$, eV	$2.4 \cdot 10^{-4}$	$1.8 \cdot 10^{-4}$	$7.5 \cdot 10^{-3}$	$2.4 \cdot 10^{-4}$	$2.1 \cdot 10^{-4}$

Here ϖ_e is the oscillation frequency, I_M is the moment of molecule inertia.

The energy of a diatomic molecule E can be represented as a sum of electronic, rotary and oscillatory energies

$$E = U_e + \hbar \cdot \varpi_e (n + \frac{1}{2}) + (\hbar^2 / 2 \cdot I_M)(j+1), \quad (2)$$

where n - oscillatory quantum number, j - rotary quantum number, U_e - energy of electronic excitation of a molecule.

The rate of the process of atom recombination (association of atoms into molecules) should be taken into account only in the case of shock waves of a low intensity. In Table 4 specified are the structure of the air and its thermodynamic functions. Using the data of these tables, it is possible to define in which case it is necessary to take into account a rate of the process of atom recombination. So, at a standard air density $\rho_0 = 1{,}29$ kg/m^3 this process should be taken into account at an abrupt change of the pressure in the front of a shock wave no more than in 20 times (when it propagates in the air with a normal pressure).

Table 4. Equilibrium structure of the air in the field of dissociation and beginning of ionization [2]

T, K	N_2	N	O_2	O	NO	N^+	O^+	NO^+
2000	0.788		0.205	0.015	0.007			
4000	0.749	0.0004	0.100	0.134	0.084			
6000	0.744	0.044	0.006	0.356	0.050			
8000	0.571	0.416	0.007	0.393	0.024			
10000	0.222	1.124		0.407	0.009	0.0034		0.0015
12000	0.050	1.458		0.411	0.003	0.020	0.0034	0.001
15000	0.006					0.096	0.015	

As in spark discharges the plasma is poorly ionized, then, accordingly, this process absorbs a small part of the electrical discharge energy. This fact allows do not take into account this process as an energy source for increasing the shock wave intensity.

Now we shall consider the problems in dependencies of shock wave intensities and discharge energy amount in gases, which arise in the process of practical realization of the latter. Let's assume that for increasing the shock wave intensity, we have chosen a way of increasing the volume power of energy release. To accomplish this purpose it is necessary to increase the discharge energy by reducing its duration and decreasing the discharge interval. If the energy accumulation source will be the condenser, then the discharge energy can be put equal to:

$$E_p = CU^2 / 2, \quad (3)$$

where C is the capacity of the condenser, U is the charge voltage. The approximate time of the discharge is defined by the formula:

$$t = C \cdot R, \quad (4)$$

where R is the resistance of a loading circuit. To select a major part of the energy in the discharge interval it is necessary, that the resistance of a feed circuit was at least by an order of magnitude less than the resistance of the discharge interval. In its turn this creates restriction on reducing the discharge interval duration.

As it is seen from (3), the discharge energy cab be increased by increasing the capacity of the condenser and/or charge voltage. If the capacity of the condenser is increased, then the discharge duration increases (as follows from formula 4), that will not allow to increase effectively the volume power of energy release. If one increases the charge voltage and assumes that the former spacing of the discharge interval is kept at the expense of inclusion in the discharge circuit of a low-inertia switch, then, even it leads to increasing the volume power of energy release, the significant increase in the shock wave intensity is not observed (as follows from the above-said).

Thus, with the purpose of exciting shock waves of a large intensity by an electrical discharge it is necessary to solve an inconsistency between the necessity to realize a significant energy release in a short time interval and to provide effective transformation of the discharge energy into the kinetic energy of gas molecules.

The results obtained can be put in a basis of developing the methods to design devices for intensive increase of the temperature of gas media with the help of the electrical discharge, as well as to analyze the dependence of the shock wave intensity on dynamic parameters of the electrical discharge.

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