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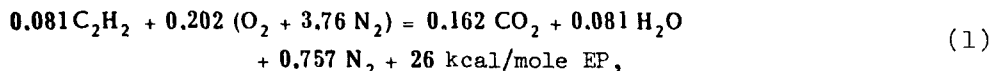
POSSIBILITY OF PRODUCING AN INVERTED MEDIUM FOR LASERS BY MEANS OF AN EXPLOSION

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In gasdynamic lasers (GDL) and amplifiers, inversion of the population of the vibrational states of certain molecules results from rapid expansion of a previously heated mixture of molecular gases [1 - 8]. The composition of the gas mixture is chosen such that when it expands the collision-relaxation times τ_1 and τ_2 of the final (1) and initial (2) laser levels satisfy the condition $\tau_1 \ll \tau_2$ [9]. In addition, the rate of the expansion should be sufficiently high so that the depletion of level 2 as a result of relaxation be slower than as a result of adiabatic cooling of the gas mixture.

In the present paper, to obtain inverted population of the vibrational levels of the molecules, it is proposed to use a new class of strongly-exothermic chemical reactions accompanied by explosion. It has been shown that in free expansion of the explosion products (EP) of certain explosive substances (ES) the aforementioned conditions can be realized without using gasdynamic devices such as nozzles or slits.

The problem consists of choosing ES whose EP have a gas composition which makes it possible to realize the required relaxation scheme, analogous, for example, to that used in known GDL [2, 10, 11]. This requirement can be satisfied by a number of gaseous and condensed ES [12, 13]. The rate of expansion of the EP, heated in accordance with the type of the ES to $(2 - 5) \times 10^3$ °K, reaches $10^5 - 10^6$ cm/sec, i.e., it is comparable with and even higher than the gas-stream velocity in GDL. The explosive reaction of an acetylene-air mixture of stoichiometric composition [14]:



can serve as an illustration.

Let us examine in greater detail the physico-chemical processes occurring during the explosion [12 - 15], confining ourselves to the case of cylindrical symmetry. Assume that a detonation wave is excited in a tube of diameter d , filled with a mixture of C_2H_2 and air. It is known [14] that at a pressure above 0.5 atm combustion goes over into detonation in an initial mixture with volume concentration 8 - 14% C_2H_2 if spark ignition is used and the tube has $d \geq 18$ mm. The velocity of the detonation wave depends little on the pressure and equals 1.8×10^5 cm/sec. An exothermal chemical reaction takes place on the front of the detonation wave and supports the existence of the wave. The reaction gives rise to EP that are thoroughly mixed into presumably a mixture of ideal gases with composition corresponding to the equation of the reaction (1). The temperature of the flame of a stoichiometric acetylene-air mixture is

of the order of 2000 - 2400°K. The heated EP are under an excess pressure that depends on the initial pressure.

If the tube is not strong, then the EP will begin to expand into the surrounding space after the detonation wave reaches the tube, and an explosion field is formed. The expansion is an adiabatically rapid process and is accompanied by cooling of the EP. Let us assume that the explosion field, which expands in time, can be approximately described by state parameters averaged over its volume. At the same time we assume that the rate of expansion of the field is determined by the rate of expansion of the explosion products behind the front of the detonation wave, the value of the latter is calculated to be of the order of 0.9×10^5 cm/sec.

In the case of cylindrical expansion of the EP of an air mixture of C_2H_2 in vacuum, the state parameters vary in such a way that the inverted population of the vibrational states 2 (00^01) and 1 (10^00) of the CO_2 molecule can occur.

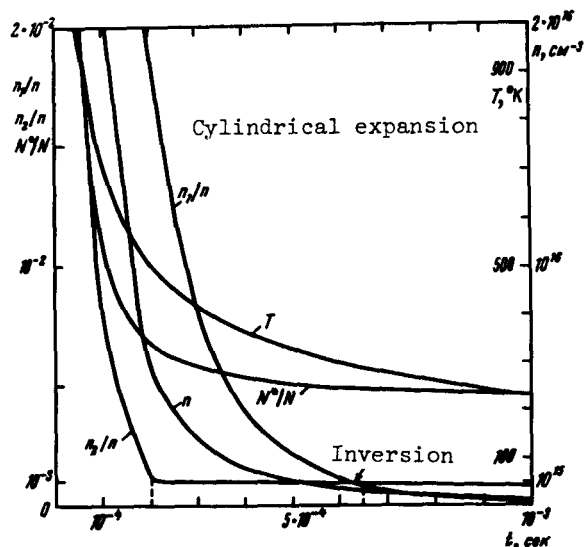
The relaxation of the excited CO_2 molecules is described approximately by the kinetic equations:

$$\frac{dn_\alpha}{dt} = W_{N^*-C} N^* n_0 \delta_{2\alpha} - \frac{n_\alpha}{\tau_\alpha(t)}, \quad (2)$$

where $\alpha = 1$ or 2 , $\delta_{2\alpha}$ - the Kronecker symbol, N^* , n_0 , n_α - concentrations of the excited molecules of nitrogen and of the CO_2 molecules in the ground state and in the α state, W_{N^*-C} is the probability of excitation transfer from the nitrogen molecule to the CO_2 , and $\tau_\alpha(t)$ is the time of the collision reaction.

For a specified expansion geometry it is possible to calculate the time dependence of the gas temperature and molecule concentration. Using also data on the temperature dependence of the collision relaxation of the CO_2 molecule [16], we can determine also $\tau_\alpha(t)$.

It should be borne in mind that at a temperature below 1000°K the relaxation of the excited CO_2 molecules is due principally to collisions with the H_2O molecules and is more probable for the lower level. However, in view of the large relative concentration of the water, the relaxation times are small and therefore at pressures in the initial mixture above 1 atm the relaxation is faster than the cooling of the gas. At the same time, at pressures below 0.5 atm no detonation is excited in the acetylene-air mixture. We have therefore chosen the following initial conditions: acetylene-air mixture at 0.5 atm pressure fills a tube with $d = 2$ cm, and after the explosion there is cylindrical expansion of the EP heated to $T_0 = 2200^\circ K$.



Time dependence of the temperature (T) of the explosion products of an acetylene-air mixture, of the CO_2 molecule concentration (n), and of the relative populations of the excited states of the CO_2 molecules (n_1/n , n_2/n) and of the nitrogen molecules (N^*/N) in cylindrical expansion. The initial conditions are given in the text.

For a qualitative analysis of the time dependence of the population of the excited states we can integrate the kinetic equations, ignoring the energy transfer from the nitrogen to the CO₂, and approximating $\tau_{\alpha}(t)$ by exponential functions. It turns out that at the specified initial conditions the relaxation of the level 1 is faster than the depletion of this level as a result of the cooling of the gas. Consequently, its population is determined by the Boltzmann factor. At the same time, the relaxation of the level 2, starting with a certain instant of time, proceeds more slowly and a difference arises between the vibrational temperature and the temperature of the random motion in the gas.

The results of the calculation of the dependence of the population densities of levels 1 and 2 on the time are shown in the figure. The abrupt change of the vibrational temperature of level 2 occurs at 200 μ sec, and the population inversion occurs 650 μ sec after the start of the expansion. The time dependence of the population density of the excited level of the nitrogen is determined mainly by the relaxation following the collision with the CO₂ molecules and is shown in the same figure. When account is taken of the energy transfer from the nitrogen to the CO₂, the inversion should be larger and should occur earlier, and in addition it takes place at larger pressures in the initial mixture.

An appreciable decrease of the inversion is possible if one uses explosives with a smaller relative concentration of water in the EP. At the same time, hydrocarbon-air mixtures can turn out to be quite effective for the production of inversion in the expansion of combustion products or in their flow through a nozzle.

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