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THE MECHANISM OF INITIATION OF CONDENSED EXPLOSIVES BY LASER RADIATION

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13 ABSTRACT

Results of studies made on the excitation of detonation of explosives by the radiation of a neodymium glass laser. An analysis of the most probable mechanism of light detonation of explosives.

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NOTICE

Earlier [1], a report was published on the excitation of detonation of explosives by the radiation of a neodymium glass laser. Light detonation of a number of other secondary explosives has since been performed, including hexogene, octogene, etc. and additional experimental material has been produced on the interaction of laser radiation with lead azide and PETN. We present below certain results of these studies and analyze the most probable mechanism of light detonation of explosives.

Method of Experimental Studies.

The investigations were performed on a laboratory installation described in [1] The duration of the laser pulse in the modulated Q mode was $5 \cdot 10^{-8}$ sec (at the half power level), and in the free generation mode -- about 10^{-3} sec. In the latter case, the radiation consisted of a series of peaks, each on the order of 10^{-6} sec in length.

The use of neodymium glass and ruby allowed studies to be performed at two wave lengths (10600A and 6943A). The intensity of the laser radiation was increased by focusing it with spherical lenses, and was decreased using a diaphragm and neutral filters.

The calibration of the measuring system and determination of the energy parameters of the laser radiation were performed using a calorimeter with a theromocouple. The accuracy of measurement of energy was no less than 10^{-2}j.

Experimental Results.

Fig. 1. shows the results of measurement of the delay of the flash of the explosive as a function of laser radiation density. In order to expand the range of investigations, experiments were performed with lead azide. This same figure shows for clarity the calculation curve. We can see that over a broad interval of change of delay, from approximately 10^{-8} to 10^{-4} sec, the energy necessary for detonation is practically constant, while it increases over 10^{-4} sec.

For a single pulseof constant length, the operating time of the explosive charge decreases with increasing incident radiation density to a certain limiting value. Fig. 2 shows the experimental dependence of the opera ing time of a charge of PETN.

With large beam diameters (d), the critical radiation density (q_{cr}) is constant, while with small beam diameters it increases (Fig. 3). The nature of the dependence for lead azide and PETN is similar, the difference being in the numerical value of the radiation density necessary for detonation and the point of change of the nature of this dependence (d_0). For lead azide, d_0=0.1 mm, while for PETN with a dispersion of 5500 cm^2/g it is about 0.6 mm, and decreases with increasing dispersion.

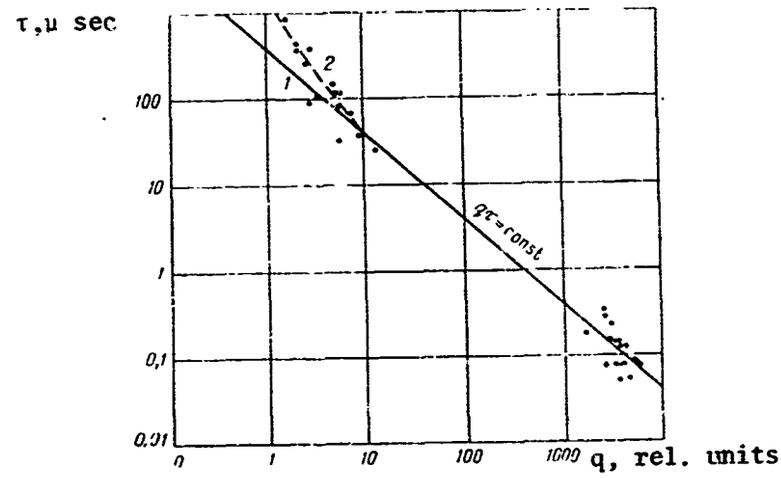

Fig. 1. Flash Delay as a Function of Laser Radiation Density. 1, Calculated Curve (Q is the Mean Value of Incident Radiation Density up to the moment of Flash of the Explosive, τ is the Time Between the Moment of Appearance of the Generator Pulse and the Flash of the Explosive); 2, Experimental Values.

This dependence of critical radiation density on beam diameter is practically retained upon transition from 10600A to 6943A wave length, which agrees with the results of measurement of the reflection factor of the explosive at these wave lengths [2]. As the pressing pressure of the explosive (P) increases, the laser radiation density necessary for detonation also increases (Fig. 4.).

The explosives studied reflect a large portion of the laser radiation which strikes them -- about 80% [2]. The addition of metal or dielectric impurities with lower reflection factor can result in a reduction in the energy loss to reflection and a corresponding decrease in the critical energy density.

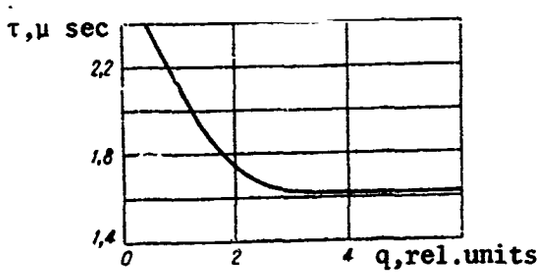

Fig. 2. Operating Time of PETN Charge as a Function of Laser Radiation Density.

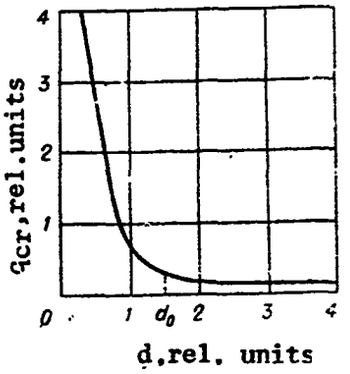

Fig. 3. Critical Radiation Density As a Function of Initiating Beam Diameter.

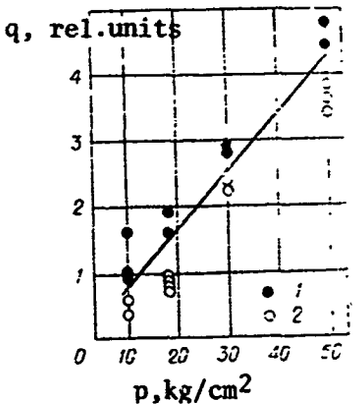

Fig. 4. Laser Radiation Energy Necessary for Detonation as a Function of Explosive Pressing Pressure. 1, Detonation, 2, Failure.

Discussion of Results.

According to contemporary concepts [4], the excitation of an explosive under the influence of an external initial pulse, regardless of the type of energy applied, can be reduced to the formation of "hot" points, in which intensive thermal decomposition of the explosive molecules occur. In general form, considering the information available from the literature on the effects of laser radiation on "passive" materials [5] and the light of ordinary sources on explosives [6], we can imagine several possible mechanisms of the formation of hot points under the influence of laser radiation.

Light impact. The radiation striking the explosive has light pressure p, the magnitude of which can be calculated according to the known formula $p = \frac{q}{c}(1+R)$, where q is the density of the incident radiation, R is the reflection factor of the light from the surface of the explosive.

With critical values of laser radiation density, this pressure is on the order of 10^{-2} kg/cm^2 for lead azide and about 1.5 kg/cm^2 for PETN. As we know, impact detonation of these explosives, even with delays of explosion of tens and hundreds of microseconds, requires several orders of magnitude more pressure. Also, in correspondence with this mechanism, the critical radiation density should drop with increasing reflection factor, while the experimental results show the opposite.

Thus, the experimental results produced cannot be explained by the influence of light pressure of the laser beam.

Initiation of the Explosive by Electrical Breakdown.

One interesting phenomenon detected in studying the interaction of laser radiation with materials is the electrical breakdown of gasses [7,8].

As we know, the explosives in question are comparatively good dielectrics. Their breakdown requires the application of a considerable electric field; in particular, the dielectric strength of pressed lead azide is on the order of 10^5 v/cm, while that of PETN is almost an order of magnitude higher.

The mean electric field intensity of a laser beam, calculated for the critical radiation density for detonation of lead azide is near $0.7 \cdot 10^5$ v/cm, for PETN -- about $8 \cdot 10^5$ v/pm. The maximum field intensity might be 3-five times higher due to local irregularities in the intensity of the laser beam across the cross section, corresponding to various oscillating modes of the laser. Although the dimensions of the areas with greater local fields are extremely small, they might serve as the locus for development of breakdown.

In the case of breakdown, during the time of a laser pulse a significant quantity of light energy might be converted to heat, comparable to that

introduced, so that electric breakdown of the explosive under the influence of laser radiation at the critical density might lead to formation of hot points.

The possibility of initiating explosives by electric breakdown also agrees satisfactorily with the studies of the influence of pressing pressure, wave length and laser radiation intensity. However, the nature of the influence of reflection factor of the explosive and pulse length, as well as the lack of differences in the initiation of explosives with dielectric and metal powder impurities contradict this hypothesis.

Thus, the possibility of electric breakdown of explosives under the influence of laser radiation cannot be eliminated, particularly under conditions of heating of the material at a center as a result of adsorption of light; however, the electric spark is not the determining factor in the process of development of detonation.

Photochemical Excitation of Explosive.

The value of a quantum of radiation from a neodymium laser is 1.17 ev, while that of a ruby laser is 1.78 ev, much lower than the value is necessary for the direct photoelectric effect in the explosives studied. However, the high electric field intensity of a laser beam requires analysis of the possibility of the multiquantum photoelectric effect, in which separation of an electron or breaking of a bond occurs as a result of simultaneous adsorption of several quanta.

Precise calculation of the multiquantum photoelectric effects in explosives is difficult. However, estimation with accuracy to an order of magnitude shows that its probability is slight and during the time of application of a laser pulse only a negligible portion of the explosive could be decomposed by this method. The qualitative course of experimental curves also disagrees with the sharply expressed dependence of the multiquantum photoelectric effect on the frequency of the electromagnetic radiation and the electric field intensity [9]. Thus, light detonation of the explosive under these conditions is not photochemical in nature.

Thermal Mechanism.

As experiments have shown, a significant portion of the radiation striking the explosive is reflected and lost, while the remaining portion is absorbed in a certain layer of the explosive material, with exponential distribution of intensity with depth. The formation of hot points in the explosive might result from adsorption of this light energy and its conversion to thermal energy.

An estimate was made of the temperature of PETN at the point of application of laser energy by solving the heat conductivity equation on a digital computer, considering energy lost to reflection, ray emission and convection. For simplicity, the influence of the thermal energy of chemical decomposition of the explosive and the kinetic energy of gas dynamic processes was not calculated. The calculations showed:

a) The loss of heat as a result of propagation of the heat wave away from the point of application of the beam is negligible during the time of a laser pulse (the characteristic parameter $\sqrt{at}$ is on the order of 10^{-4} mm, while the size of the initial center of adsorption of light energy is on the order of 10^{-2} mm). It has a significant influence on the energy balance only with long laser pulses (on the order of 10^{-4} sec and higher), causing an increase in the detonation energy (see Fig. 1);

b) With critical densities of single-pulse radiation, the maximum temperature in the center might reach 1500°K, which corresponds in order of magnitude with the critical temperature of PETN under these conditions [4];

c) At these temperatures, the losses of energy due to ray emission from the heated surface of the explosive are several orders of magnitude less than the energy introduced. Thus, the energy of the laser radiation, with the exception of losses to reflection, is extended primarily in heating the explosive within the volume of initial energy input, limited by the diameter of the beam and the depth of penetration of electromagnetic radiation into the explosive.

The introduction of relatively high quantities of energy to the initiation center in a short period of time naturally causes an increase in pressure. According to our estimates, it is on the order of 10^4 kg/cm^2, and is comparable to the critical pressure of the same explosives during impact initiation. One indirect confirmation of the high pressure at the initiation center is the constantcy of the reflection factor of the explosives studied practically up to the point of explosion, with increasing incident energy density.

Thus, when explosives are initiated by laser radiation, the temperature and pressure at the initiation center are comparable in order of magnitude to the values of these parameters achieved with other known methods of detonation. Of course, the actual pressure and temperature at the center, as well as the shock wave leaving the center will differ slightly due to the influence of gas dynamic processes and chemical decomposition of the explosive. The estimates which we have presented characterize simply the order of magnitude of these parameters.

The thermal hypothesis allows us the explain the entire complex of results of experimental study of laser detonation of explosives. This hypothesis clarifies the decrease in critical radiation density with decreased reflection factor of the explosive, the lack of difference in this parameter

for the two wave lengths studied, which are in the area of weak adsorption of explosives, as well as the influence of pressing pressure of the explosive, the change in the operating time of the charge with increasing density, etc.

This last dependence indicates that the velocity of the initial shock wave during excitation of an explosive at minimum energy is near the critical detonation velocity of the charge under these conditions and increases with increasing radiation density to the limiting detonation velocity, resulting in the existance of a limit for decreasing operating time of an explosive charge. Furthermore, the experimental dependence of critical radiation density on beam diameter indicates that with large beam diameters, the parameters of the initial shock wave are constant, while in the area of small dimensions, comparable with the critical diameter of the charge and the dimensions of the reaction zone, they increase.

Thus, analysis of the experimental results of detonation of PETN and lead azide from the standpoint of a number of possible physical processes, has shown that only the thermal theory of initiation can explain the facts produced. In this case, the light energy is adsorbed by a layer of the explosive and is converted to the energy of a shock wave, which is the criterion for the initiating capacity of laser radiation under various conditions.

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