Explosion of water drop bombarded by a series of optical-radiation pulses

V. V. Kostin, V. A. Pogodaev, S. S. Khmelevtsov, and L. K. Chistyakova

P. N. Lebedev Physics Institute, USSR Academy of Sciences
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Explosion of a water drop acted upon by a number of radiation pulses of wavelength of 2.36 μm and peak intensity 10^8 W/cm^2 is investigated. The explosion energy thresholds, expansion patterns of the explosion products, and the rate of drop evaporation near the threshold values of the incident radiation power are measured.

The passage of a high-intensity light beam through a liquid leads to different optical-hydraulic effects. Effects produced when a ruby-laser beam is focused into a large volume of liquid were first considered in[1]. It was shown that at the place where the light energy is concentrated, the liquid comes to a boil explosively at small energy inputs. The possibility of explosion of a water drop when it is rapidly heated by laser radiation was first demonstrated by us in[2-4]. The explosion of a drop of aniline solution was initiated in[4] by a single ruby-laser pulse of $\sim 10^{-3}$ sec duration. In this communication we present the results of an investigation of the explosion of a drop of pure doubly-distilled water bombarded by a series of short pulses, and analyze the possible causes of this effect.

A drop of distilled water, of 320–400 μ diameter, suspended on a filament of 6–11 μ diameter, was acted upon by a dysprosium-doped calcium-fluorite laser of wavelength 2.36 μ, producing pulses of 400 Hz repetition frequency and 40 nsec duration[1)]. The average density of the radiation power focused on the drop was 3 kW/cm^2. The peak power density was approximately 2×10^8 W/cm^2; the area of the focal spot was 0.2×10^{-2} cm^2. The center of the light spot was aligned with the center of the drop with accuracy ±10 μ with the aid of a lens of F = 3 cm.

The measurements were made with the aid of the apparatus and procedure described in[6]. Prior to the explosion, we investigated the rate of change of the drop radius, using motion pictures produced at 10^3 frames/sec, and then registered the occurrence of the explosion and measured the expansion patterns produced following the explosion.

Figure 1 shows the variation of the drop radius with time following periodic irradiation by pulses of power density 5.6×10^7 W/cm^2. Termination of the curve means explosion of the drop; the explosion process lasted less than 0.5 msec; this time is of the same order as the time of expansion of the drop, which we measured in[4] with the aid of a "time magnifier." Evaporation from the surface of the particle takes place prior to the instant of the explosion.

A typical expansion diagram of the drops obtained by explosion of a large drop is shown in Fig. 2. A feature of the diagram is the predominant expansion of the particles into the hemisphere into which the radiation propagates. This indicates that the explosion is not central. The deficit of the particles in the direction close to the direction of the acting beam is due to the fact that they are acted upon by pulses of high-power radiation that cause them to evaporate or to explode. The explosion of the drop by the first pulse was observed at an average power density of the applied radiation ~ 2 kW/cm^2.

The cause of the observed explosion may be superheating of the drop material when the radiation energy is dissipated into heat, or local superheating due to dissipation of the acoustic waves produced in the drop under the influence of the powerful pulse of nanosecond duration following surface or volume absorption of the energy, or else as a result of stimulated Mandel'shtam-Brillouin scattering.

Let us estimate the effective density of optical energy of wavelength 2.36 μ needed to initiate thermal explosion of the drop. According to[4], this quantity is given by

$$\varepsilon K_{\mathrm{abs}} \geq {}^2/_3 C\gamma r_0 (T_{\mathrm{cr}} - T_{\mathrm{b}}). \tag{1}$$

Here K_{abs} is a measure of the efficiency with which the radiation is absorbed by the water, γ and C are the density and specific heat of the water, r_0 is the initial radius of the drop, ϵ is the density of the optical energy on the drop during the action, T_{cr} is the critical temperature, which in this case corresponds to the superheat temperature, and T_b is the boiling temperature. The threshold energy ϵK_{abs} under the experimental conditions amounts to 4.01–4.53 cal/cm^2. Under the conditions of our experiment, the explosion occurred with energy pumped into the drop at a threshold value ϵK_{abs} = 0.32–0.37 cal/cm^2, and no thermal explosion could occur as a

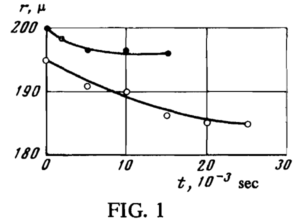

FIG. 1

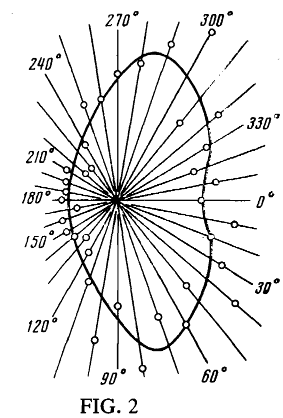

FIG. 2

FIG. 1. Time variation of the radius of a drop periodically bombarded by pulses of density 5.6×10^7 W/cm^2.

FIG. 2. Expansion diagram of small drops, obtained following explosion of a drop with initial radius 200 μ. The polar radius corresponds to the number of particles ejected by the explosion in a given direction. The light pulse is directed along the 180°–0° axis.

result of direct heating of the drop by the radiation.

The absorption coefficient α_{abs} of radiation with wavelength 2.36 μ is 40.4 cm^{-1}; the value of α_{abs} determines the ratio of the drop radius to the mean free path of the radiation in the water, r/l_{abs}, which was varied in the experiments between 0.66 and 0.84. Thus, the most probable effect that leads to explosion of the drop is dissipation of the acoustic waves generated following volume absorption of the radiation[7].

[1)]The laser was developed and constructed in the Oscillations Laboratory of the Physics Institute of the USSR Academy of Sciences [5].

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