to obtain holograms at convergence angles up to 10° and at distances to the object on the order of several meters; the latter can be estimated from the formula $R = \sqrt{I/2\pi W'}$, where I is the energy of the radiation reflected from the object.

Upon reconstruction of the wave front, two images could be observed, symmetrical about the central beam. One of them is shown in Fig. 2. Longitudinal displacement of the lens changes the distance from the point source to the film. This causes one of the reconstructed images to become gradually less sharp and to vanish, corresponding to a transition from Fourier holography to Fresnel holography.

The experiments have shown that in order to improve the pulsed holography it is necessary to increase the spatial coherence of the ruby laser, by producing effective methods of transverse-mode selection and by greatly increasing the resolution of the films, which is of importance also for image noise suppression [4].

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OPTICAL BREAKDOWN "FIREBALL" IN THE FOCUS OF A LASER BEAM

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It is known that optical breakdown of gas in the focus of a laser beam (see the review [1]) is of explosive nature, owing to the short time and the large concentration of the absorbed-light energy, and that the resultant shock wave can be described sufficiently well by the solutions obtained in the case of the so-called strong explosion.

We show in this article that the light spark exhibits also another feature characteristic of a strong high-temperature explosion, namely the so-called "fireball" (see, for example, [2]), which is a strongly ionized region from which a shock wave is detached and moves forward when its ionizing action is noticeably weakened. The fireball (FB) is produced by the shock wave during that period when it exerts the strongest ionizing action (during the first stage, owing to photoionization, the FB front may lead the shock wave front). The following semiempirical relations [2] characterize the fireball as a function of the energy input, the FB radius at the instant of shock wave detachment $R_{FB} \approx AE^{2/5}$, where $A \approx 3 \times 10^3$ cm/(kt)$^{2/5}$, the time preceding the detachment, the time dependence of the radius, the maximum FB dimension, and its lifetime.

In our case the micro-explosion was produced by optical breakdown of air in the focus of the beam of a Q-switched laser producing a flash of 1 J energy in 30 nsec. The volume occupied by the concentrated plasma was investigated by measuring the perturbation of an external magnetic field.

The volume in which the initial energy was released was elongated in form, since the volume of the focal region had a longitudinal dimension z_f exceeding by several times the transverse radius ρ_f ($\rho_f/z_f \approx d/4f$, where the beam diameter at the lens was $d \approx 1$ cm and the focal distance of the lens was $f \geq 5$ cm). The volume of the "fire cloud" was simulated by a spheroid with semi-axes a and b, the transverse semi-axis b being larger than ρ_f, so that the scattering took place at high velocities. Experiment has shown that the magnetic moment increases within a time on the order of 100 nsec (see Fig. 1), which is several times longer than the light-energy input time, and the ratio of the magnetic moment to the external magnetic field is $M/H_0 \approx 10^{-5}$ cm^3. The effective volume from which the field is pushed out can be estimated with the aid of the expression for the magnetic moment of a superconducting spheroid in an external magnetic field, $M \approx -VH_0/4\pi(1 - n) \approx -VH_0/4\pi$ (since the demagnetization factor is $n \ll 1$ for a prolate spheroid), i.e., $V_{eff} \approx 4\pi M/H_0 \approx 10^{-4}$ cm^3.

Let us compare this volume with the volume of the FB at the instant when the shock wave is detached from it, using the semi-empirical formula given above for R_{FB} of a spherical explosion. The volume is

$$V_{FB} \approx \frac{4\pi}{3} R^3_{FB} \approx 4A^3E^{6/5} \approx 10^{-4} \text{ cm}^3$$

for $E \approx 1$ J $\approx 3 \times 10^{-13}$ kt. Thus, the volume of the forced-out magnetic field is of the same order of magnitude as the volume of the FB at the instant of shock-wave detachment, this being due to the sharp decrease in the ionizing action, conductivity, and diamagnetism of the front of the shock wave itself after the detachment from the FB.

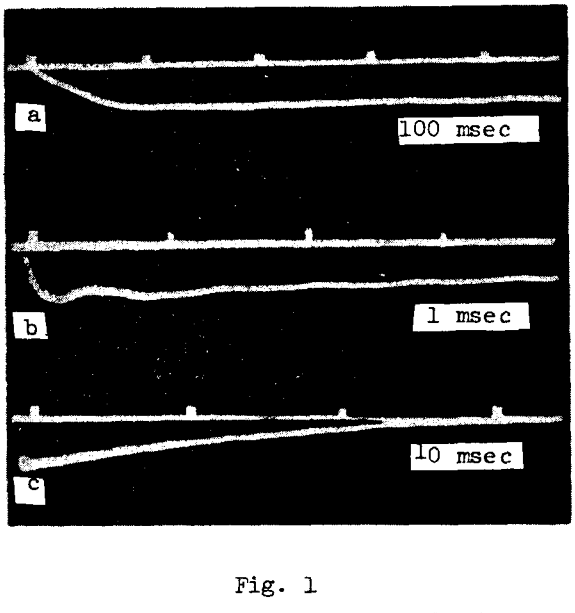

Fig. 1

Let us estimate the rate of motion of matter at the instant of shock-wave detachment, using first the solution [2] for a strong pointlike explosion, $R(t) \approx (E/\rho_0)^{1/5}t^{2/5}$, and assuming that detachment occurs at $\dot{R} = C_{cr}$, which is the critical velocity at which the ionization decreases abruptly. Then the detachment time is $t_{cr} \approx (E/\rho_0 C^5_{cr})^{1/3}$, and using the data of [2], $t_{cr} \approx 10$ msec at $E \approx 20$ kt, we obtain $C_{cr} \approx 10^6$ cm/sec.

Using the solution for a cylindrical shock wave, $R^2 \approx (E/\rho_0 \ell)^{1/2}t$, we obtain for the instant of detachment $t_{cr} \approx (E/\rho_0 \ell)^{1/2}(1/C^2_{cr})$. For our case, $E \approx 1$ J, $\rho_0 \approx 10^{-3}$ g/cm^3, a length $\ell \approx 2a \approx 0.1$ cm and $C_{cr} \approx 10^6$ cm/sec, we obtain $t_{cr} \approx 10^{-7}$ sec, which is close to the growth time of the magnetic moment (see Fig. 1, which shows a signal proportional to M at three sweep rates with time markers separated 100 nsec (a), 1 μsec (b), and 10 μsec (c)).

The magnetic moment of the "fire cloud" is

$$M \approx -VH/4\pi \approx ab^2 H_0/3 \approx -l R_{cr}^2 H_0/6,$$

but $R_{cr}^2 \approx (E/\rho_0 l)/C_{cr}^2$, and therefore $M \approx -EH_0/6\rho_0 C_{cr}^2 \sim E/\rho_0$ neglecting the possible weak dependence of C_{cr} on certain quantities. (This dependence can be estimated, for the case when the magnetic field is forced out, from the condition that the expansion rate C_{cr} be equal to the rate of penetration of the magnetic field $v_H \approx c^2/4\pi\sigma\delta$, where σ is the conductivity and δ the thickness of the penetration layer. For $\sigma \approx T_{cr}^{3/2} \approx R_{cr}^3$ and $\delta \approx \alpha R_{cr}$, we get $C_{cr} \approx B/R_{cr}^{1/4}$. This yields $M \approx E^{4/3}/\rho_0^{4/3} l^{1/3}$.)

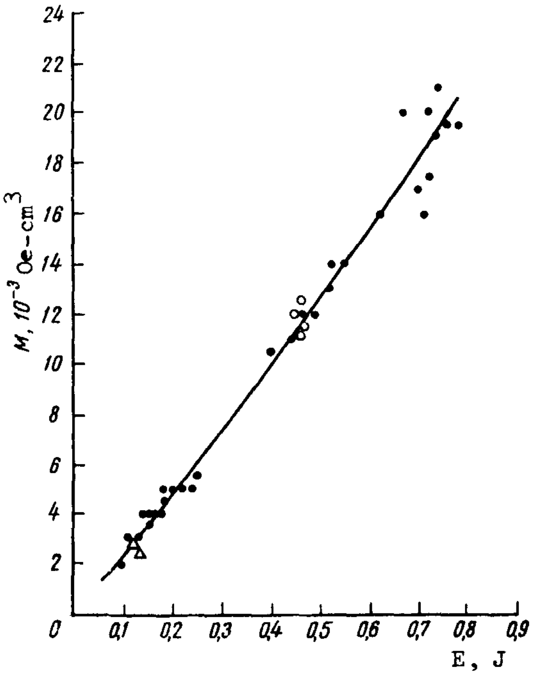

Fig. 2

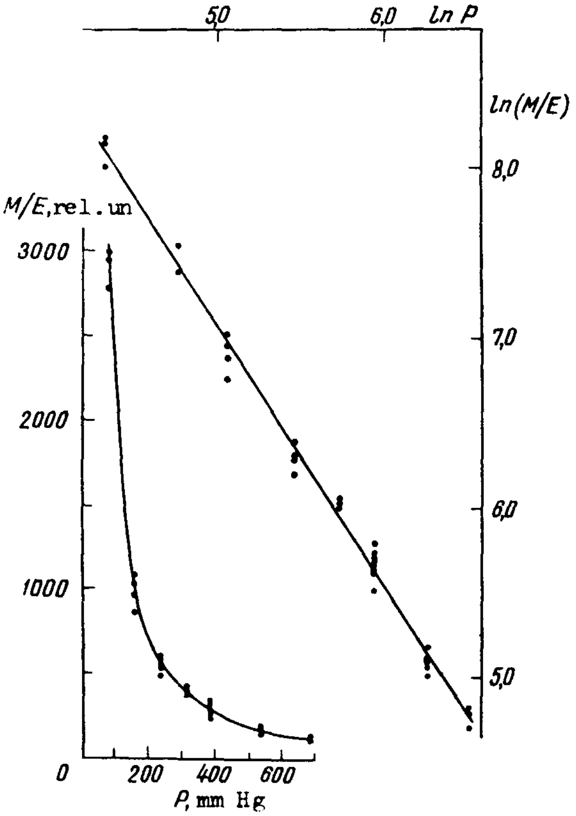

Fig. 3

Figure 2 shows the experimentally obtained dependence of M on the energy E released in the spark. The latter was determined from the difference in the readings of two calorimeters which measured a definite fraction of the incident and transmitted light energies. The obtained M(E) relation is nearly linear. Figure 3 shows a plot of M/E against P_0, which is nearly reciprocal.

In conclusion we compare the "lifetime" of the FB, $T_{FB} \approx BE^{1/2}$, where $B \approx 10$ sec/(kt)$^{1/2}$ [2], with the "lifetime" of the magnetic moment. For an input E ≈ 1 J, this time is T ≈ 10 μsec, which coincides in order of magnitude with the lifetime of the magnetic moment (Fig. 1). Thus, the FB model explains satisfactorily a large number of phenomena.

We are grateful to graduate student L. Kolomiitsev for taking part in the experiment.

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ERRATA

The article by G. A. Askar'yan et al., V. 5, No. 5, p. 150 (transl. p. 121) calls for the following errata and comments:

1. The sweep durations on the oscillograms of Fig. 1 are incorrectly marked. Instead of 100 msec, 1 msec, and 10 msec read 100 nsec, 1 μsec, and 10 μsec (as written in the text).

2. The formula for the fireball lifetime (more accurately, the expansion time of the fireball, which should be compared with the duration of the diamagnetic perturbation) contains errors.

It should read $T_{FB} \simeq BE^{1/3}$, where $B \simeq 0.3\ \mathrm{sec/(kt)}^{1/3}$ and E is the explosion energy in kilotons.

3. At high temperatures, when the adiabatic constant of the gas $\gamma \to 1$, the main energy of the shock wave is contained in the internal energy of the gas behind the compression layer, but since this energy is proportional to the kinetic energy, all the relative estimates (evaluation of conditions) of the detachment of the shock wave from the fireball, based on the assumed equality of the wave kinetic energy to the initial released energy, remain in force, but in absolute estimates of the velocity and time of detachment it is necessary to introduce a coefficient that takes into account the difference between the total and kinetic energies of the shock wave.

A more detailed theory of fireballs with allowance for the losses will be published soon.