

## Letters to the Editor

### THE EFFECTS OF A LASER BEAM IN A LIQUID

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Submitted to JETP editor February 28, 1963

J. Exptl. Theoret. Phys. (U.S.S.R.) 44, 2180-2182 (June, 1963)

THE conditions and results of the passage of a light beam through liquids can be completely changed with the high intensity beam available from a laser. In particular, local heating of the liquid makes possible the formation of bubbles and effervescence in the light beam on account of the formation of vapor or elimination of dissolved gas, and this can lead to anomalously large scattering of the light by the bubbles and to various photohydraulic effects.

#### 1. Effervescence of liquids in the light beam.

We have performed experiments on the effervescence of transparent and absorbing liquids in the intense beam of a ruby laser with a pulse length of  $\sim 1 \mu\text{sec}$ .



FIG. 1. Effervescence of tap water in an unfocused beam.

We observed and photographed the formation of bubbles in ordinary tap water in a beam focused deep in the liquid and in an unfocused beam (Fig. 1). When the beam intensity is reduced the formation of bubbles in the same water was not observed.

Aerated water boils intensely in the light beam even at low beam intensity (Fig. 2). Figures 1 and 2 were obtained in the scattered light of the laser beam without additional illumination. Special controlled experiments showed that the light scattering occurs just on the impulsively forming bubbles and not on inhomogeneities in the liquid.

The effervescence of transparent liquids in a powerful light beam is facilitated not only by the presence of dissolved gas, metastability of states, or nearness to the boiling conditions. Of particular interest to us is the role of tiny inhomogeneities, which are always found in real liquids. Such inhomogeneities as have large absorption coefficients are strongly heated and serve as centers for the local heating up, vaporization, and boiling of the liquid. The order of magnitude of the beam density required for the formation of bubbles on inhomogeneities can be estimated. This density  $I \gtrsim (\kappa/\alpha\delta) \epsilon_0$ , if the diameter of the inhomogeneity  $a \geq \delta$ ; and  $I \gtrsim (\delta/a)^2 (\kappa/\alpha\delta) \epsilon_0$ , if  $a \ll \delta$ , where

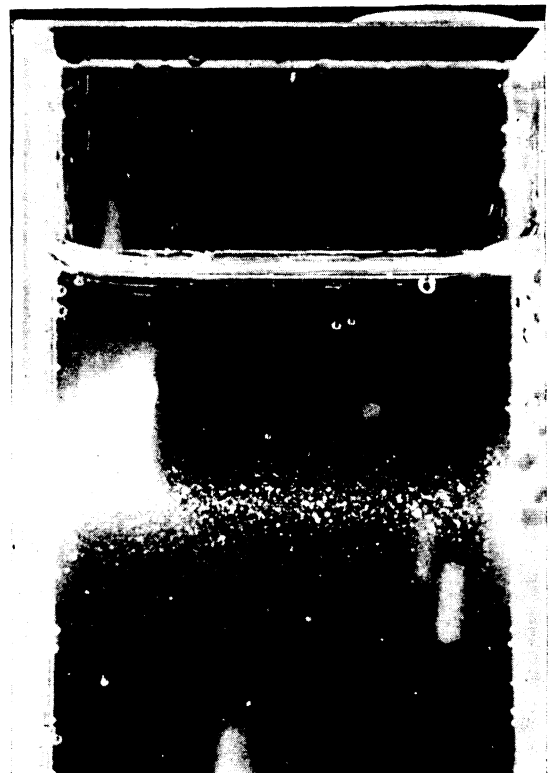


FIG. 2. Effervescence of aerated water in an unfocused beam.

$\delta$  is the thickness of the layer of liquid which it is necessary to vaporize or de-gas to create a bubble of the specified size,  $\alpha$  is the portion of the light beam going into heating the liquid,  $\kappa$  is the thermal conductivity of the liquid,  $\epsilon_0$  is the energy required to vaporize or de-gas a unit volume of liquid. If we take for water  $\kappa \approx 10^{-3}$  cm<sup>2</sup>/sec,  $\epsilon_0 \approx 2.5$  kJ, then for a  $\sim \delta \sim 10^{-3}$  cm, we find  $I$  to be of the order of a few kW/cm<sup>2</sup>.

The bubbles of vapor that have been formed grow to an optimum size and, after the intensity of the beam falls off, disappear in a time  $\tau \sim r^2/\kappa$ . A portion of the bubbles can remain on account of the diffusion of dissolved gas in the liquid. We have observed such bubbles in ordinary water in a magnifying tube after a flash. Their diameters reached 0.06 mm with a floating rate of  $\sim 0.1$  cm/sec and number  $\sim 30-50$  per cm<sup>3</sup>. In aerated water the left-over bubbles were larger by far. They ascended quickly at the rate of  $\sim 1$  cm/sec, forming a thick foamy layer after the light flash.

**2. Scattering of light from the bubbles.** The formation of bubbles on inhomogeneities in the light beam can strongly increase light scattering in the liquid. Therefore, at high intensities it is impossible to use the known data on scattering of light in liquids. The true inverse depth of scattering,  $1/l(x,t) = -I^{-1} \partial I / \partial x$ , will depend on the intensity and transmitted energy of the light beam. For example, if the volume of a bubble is determined by the quantity of vapor produced by the heat evolved at an inhomogeneity of radius  $a$ , then

$$\frac{1}{l} \approx n(I_0) \gamma \pi \left( \frac{3a^2 \alpha}{4\lambda \rho_n} \right)^{2/3} \left\{ \int_0^t I(x, t) dt \right\}^{1/3},$$

where  $\lambda$  is the heat of vaporization and  $\rho_n$  is the vapor density of the liquid,  $n(I_0)$  is the number of nascent bubbles,  $\gamma$  is the ratio of the scattering cross-section of the bubbles to the area of their geometrical cross-section. This scattering depth can become many times less than the depth of absorption and scattering of light of low intensity. (The ratio of the depths of scattering by bubbles and absorption by the inhomogeneities giving rise to them is

$$\frac{l_a}{l_r} \sim \frac{r^2}{a^2} \sim \left( \frac{\alpha I_0 t}{a \lambda \rho_n} \right)^{2/3} \sim 10^2$$

for  $\alpha I_0 t \sim 10$  J/cm<sup>2</sup> and  $a \sim 10^{-3}$  cm.)

At high light intensities and vigorous boiling one can expect a fusion of the bubbles and formation of a channel of vapor by means of displacement of the liquid from the beam volume.

The scattering processes were examined in

two ways. Signals from photomultipliers which read the light from the flashes passing through the liquid and not passing through the liquid were fed to an oscillograph, and the changes in shape of the signals with time were compared. It was found that the character of the scattering changes with time as the scattering centers increase in effectiveness. Experiments were also carried out with a bolometer measuring the total energy of transmitted light. These showed a weakening of the light going through when the liquid was aerated, when the light was focused inside the liquid, and when other means of increasing the boiling process were used.

**3. Photo-hydraulic effects.** Effects arising from focusing the light close to or on the surface of a buoy immersed in the liquid were examined. At the places where energy is extracted explosive boiling will occur for small energy contributions (at the present time pulse lengths of several nanoseconds have been attained). Such a photo-hydraulic effect can exert a strong mechanical action on the surface, similar to the action of the well-known electro-hydraulic effect. We have observed already in our millisecond flashes various photo-hydraulic effects by focussing the light onto

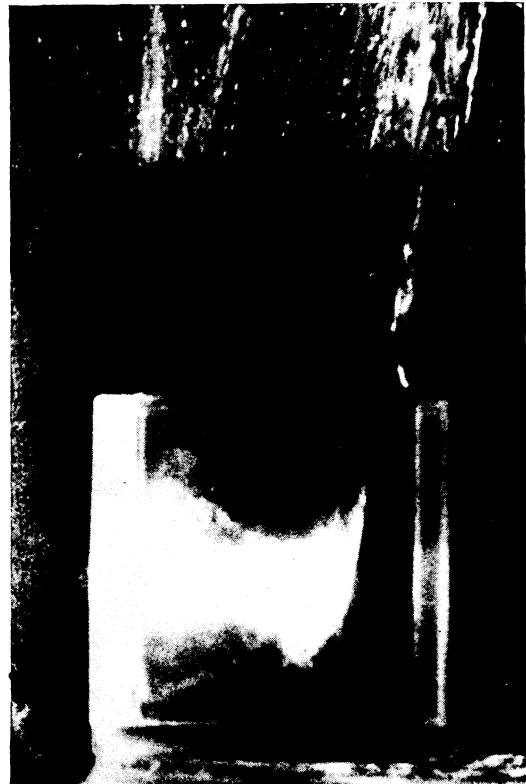


FIG. 3. Cumulative ejection of colored liquid from its cuvette under the action of focussed light (the penetration region is seen in the scattered light from the bubbles).

a submerged plate: caving in and squeezing out of the plate, a change in the nature of the puncture of the plate by the light beam compared to puncture in air, rupture of the cuvette by shock waves, ejection of the liquid from the place where the plate burns through.

Increasing the absorptive power of the water (by coloration with copper sulfate, which absorbs the ruby laser light quite well) led to a sharp intensification of the photo-hydraulic effects. A strong ejection of liquid, cumulative in nature, was observed (Fig. 3). The height of the ejected stream reached a meter, and on some occasions almost all the water in the cuvette was ejected. Experiments conducted with colored liquids provide models for the effervescence processes in the beam of infrared lasers, the radiation of which is strongly absorbed by water.

The effects considered can increase many fold the amplitude of the pressure waves created in a liquid by a light beam incident on its surface. The amplitude even of the nonshock waves of compression during boiling is determined by the vapor pressure of the liquid at the temperature of local heating and can exceed by a million times the direct light pressure. The subsequent expansion waves can intensify the boiling and breakdown of the liquid.

In conclusion we thank V. S. Zuev and V. K. Konyukhov for their participation in the preliminary experiments on effervescence of aerated liquids carried out in the summer of 1962.

Translated by L. M. Matarrese  
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### ABRUPT CHANGE IN PROBABILITY OF THE MÖSSBAUER EFFECT AT THE PHASE TRANSITION IN FERROELECTRICS

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Submitted to JETP editor March 28, 1963

J. Exptl. Theoret. Phys. (U.S.S.R.) **44**,  
2182-2183 (June, 1963)

IT is known that a ferroelectric phase transition is accompanied by a change in the structure and in some of the physical properties of crystals. In such a transition one would expect anomalous changes of the parameters of the resonance absorption of  $\gamma$  rays (for example, the probability of recoilless resonance absorption, shift of the resonance energy, etc).

We have attempted to detect such anomalous changes in the series of solid solutions  $\text{BiFeO}_3 - \text{SrSnO}_3$ . Bismuth ferrite is a ferroelectric anti-ferromagnet (Curie and Néel points  $850$  and  $360^\circ \text{K}$ , respectively<sup>[1,2]</sup>), while strontium stannate is a compound without any special dielectric and magnetic properties. Both compounds have the perovskite structure. One would therefore expect to find a continuous series of ferroelectric solid solutions for this system over a wide range of compo-

sition on the  $\text{BiFeO}_3$  side. X-ray analysis shows that at room temperature, up to approximately 45 mole % of  $\text{SrSnO}_3$ , just as in pure  $\text{BiFeO}_3$ , the solid solutions are in the rhombohedral, ferroelectric modification.

The source for the measurements of resonance absorption of  $\gamma$  quanta was the  $\text{Sn}^{119*}$  isomer contained in  $\text{SnO}_2$ .<sup>[3]</sup> The absorbers of the different solid solutions contained the same weight ( $17 \text{ mg/cm}^2$ ) of  $\text{SrSnO}_3$ . The resonance absorption in a  $\text{SrSnO}_3$  crystal had been studied earlier.<sup>[4]</sup> Figure 1 shows the temperature dependence of the maximum absorption  $\epsilon(0)$  for these absorbers. A sharp change in  $\epsilon(0)$  for the solid solutions was found at certain temperatures which decreased with increasing concentration of  $\text{SrSnO}_3$ . The widths of the spectra taken at temperatures immediately above and below the region of the "transition" do not differ noticeably. This means that the sharp change in  $\epsilon(0)$  at the temperature of the "transition" is almost entirely caused by an

FIG. 1. Temperature dependence of maximum absorption  $\epsilon(0)$  for absorbers of solid solutions of  $\text{BiFeO}_3 - \text{SrSnO}_3$  (absorber contains  $17 \text{ mg/cm}^2$  of the  $\text{SrSnO}_3$  component). The numbers on the curves give the mole % of  $\text{SrSnO}_3$ .

