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THE INTERACTION OF 10·6 μm LASER RADIATION WITH LIQUIDS

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Abstract The interaction of a pulse from a TEA laser with the free liquid surface of water and chloroform, is recorded by high-speed photography. The phenomena is similar to the high velocity impact of a projectile with a liquid or solid surface.

A vapour cloud, above the liquid, expands with an initial velocity of 1500 m s^{-1} and a violent disturbance below the liquid surface is observed. In the case of chloroform, a cloud of small bubbles is produced. A shock wave model is proposed to account for the disturbance below the surface of the liquid.

INTRODUCTION

The efficient application of lasers to machining processes such as drilling, cutting and welding depends upon the absorption of the laser energy at the surface of the solid. Differential absorption of laser radiation at absorbant regions on reflecting surfaces has been exploited in such applications as cavity drilling in dentistry and the typewriter 'eraser'.

In recent years the CO_2 laser has been developed into a range of engineering instruments and the latest transversely excited atmospheric (TEA) CO_2 lasers possess high energy and power together with compactness. However, the output wavelength of 10·6 μm is strongly reflected by most metals and some of the advantages in terms of high electrical–optical energy conversion may be lost because of poor energy coupling at the surface.

Siegrist *et al.*(1,2) have shown that thin liquid coatings increase the energy transfer between the laser radiation and the solid. Electron micrographs of water-coated solids irradiated by focussed CO_2 laser pulses exhibit fracture which may be due to the generation of intense shock waves in the liquid–solid system.

The work described here is concerned with initial experiments to discover the processes which occur when a pulse from a TEA CO_2 laser is incident upon a free liquid surface. The interaction with water and chloroform have been studied using high-speed photographic techniques.

In general the interaction of a laser beam at any surface may be considered to take two forms. When the laser power is sufficiently high, a spark occurs at the material-gas interface; the event is similar to that which occurs in a gas at the focus of a lens. A luminous plasma is formed with the emission of optical and acoustic energy. At laser power densities below the threshold for breakdown at the surface, laser radiation is absorbed and reflected. In water and many organic liquids the absorption coefficient is high at 10·6 μm and heating of a thin layer on the surface takes place.

EXPERIMENTS

A pulse from a TEA CO_2 laser(3) with an output of ~ 1J in a pulse 80ns FWHH was focussed just below the free surface of the liquid to prevent air breakdown and

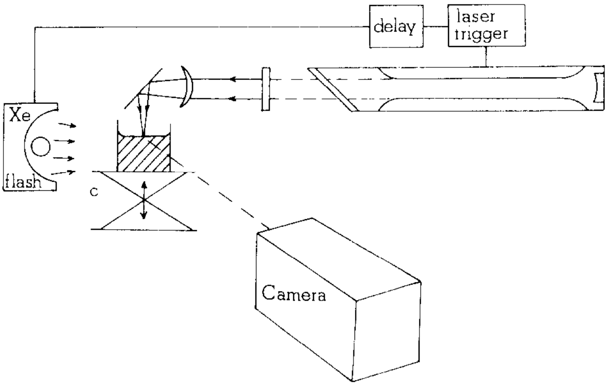


Fig. 1. Experimental arrangement.

was incident on to the horizontal surface of water and chloroform in a cubic glass cell, Fig. 1. The interaction was illuminated by Xenon flash sources and the event recorded by cameras at right angles to the illuminating radiation and the laser radiation. Two light sources were used. The first a short duration, ~ 5 μs, system incorporating an EGG FX6A Xenon lamp in conjunction with a delay unit and 35mm SLR camera, gave snap shot photographs of the event. Secondly, a conventional long duration, $>100\,\mu$s, photographic flash unit was used with an Imacon image converter camera to give high-speed framing photographs of the event. The Imacon camera had framing rates of 10^6 and 10^5 frames per second with corresponding exposure times of 200ns and 2 μs per frame respectively.

RESULTS

In the case of water, a plume of vapour with high optical scattering power is produced above the surface and is clearly visible under side illumination. Figure 2 shows a series of photographs taken with the 5 μs light source.

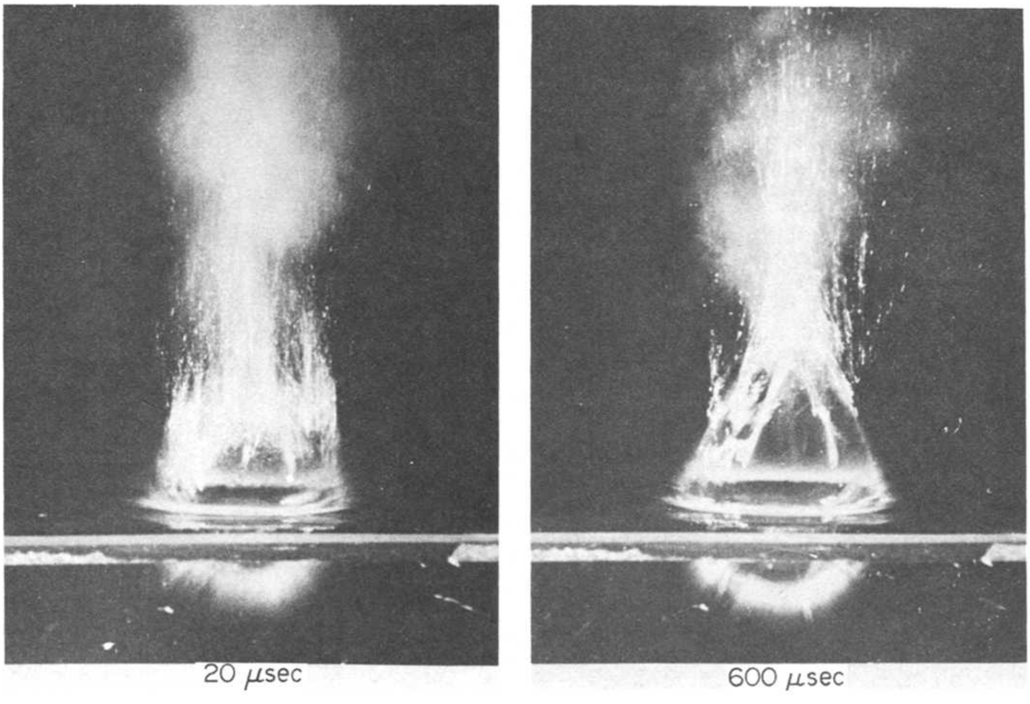
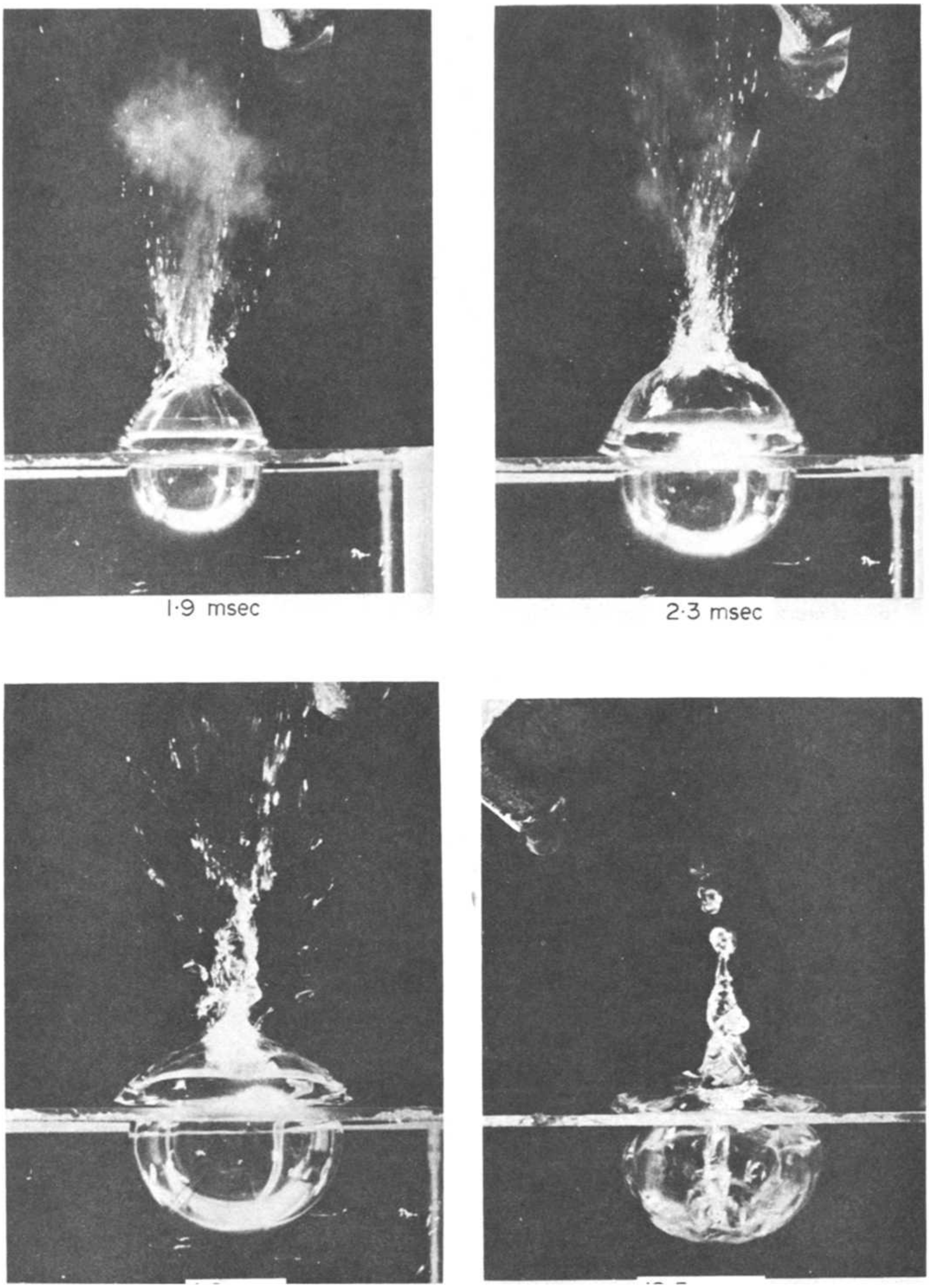


Fig. 2.



1·9 msec

2·3 msec

Fig. 2. Series of 5 μs exposure photographs of the laser–water interaction.

A gas bubble is generated below the surface which expands with time. This bubble is apparently driven by the evaporating liquid from the surface. During the first tens of microseconds after the laser pulse the bubble is not well defined. However, as time proceeds the bubble surface can be seen and this continues to expand into the liquid. The later stages exhibit violent disruption of the water, both on and below the surface. In many cases the bubble detaches and travels to the bottom of the water cell. At the

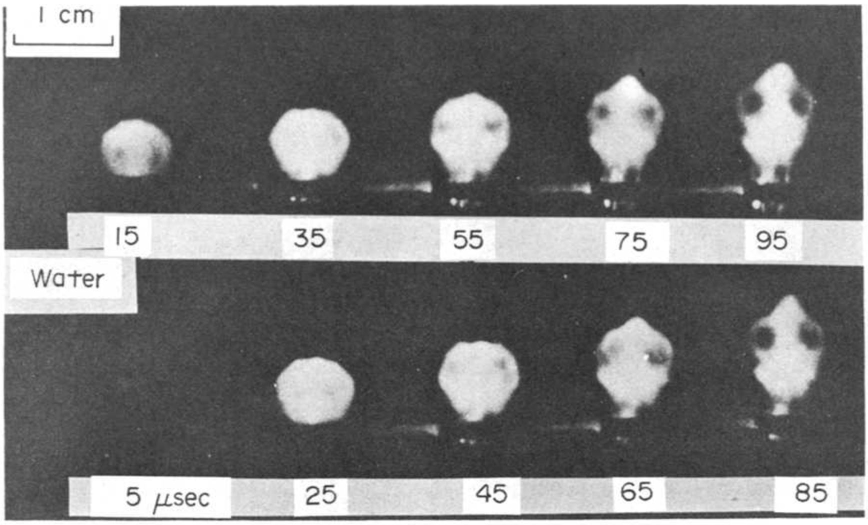


Fig. 3. Water 10^5 frames s^{-1}.

same time a fountain effect occurs and water droplets are ejected from the laser interaction region on the surface. The interaction process shows striking similarities with the high velocity impact of projectiles with solid targets.(4)

Figure 3 shows a sequence of high-speed photographs of the laser water interaction. The development of the vapour cloud can be seen above the surface and the initial velocity of the expanding front is ~ 1500 m s^{-1}. At 7 μs after the laser pulse the front velocity has fallen to ~ 750 m s^{-1}. The evaporate velocity is greater than the sound speed in air (~ 300 m s^{-1}) and therefore a shock wave and associated small report are generated. Below the water surface an expanding bubble is generated but this is difficult to measure due to its small size.

In order to increase the magnitude of the effects at the liquid surface, water was replaced by chloroform. This has a lower boiling point (62°C) and latent heat of vaporization (264 J g^{-1}) and consequently the volume of chloroform evaporated is ~5× that of water with the same incident laser energy.

Figure 4 shows the interaction at the chloroform surface with a framing rate of $10^6 s^{-1}$. In this case it can be seen that the visible disturbance below the surface preceeds that above. However, a single bubble is not visible and the disturbance consists of many

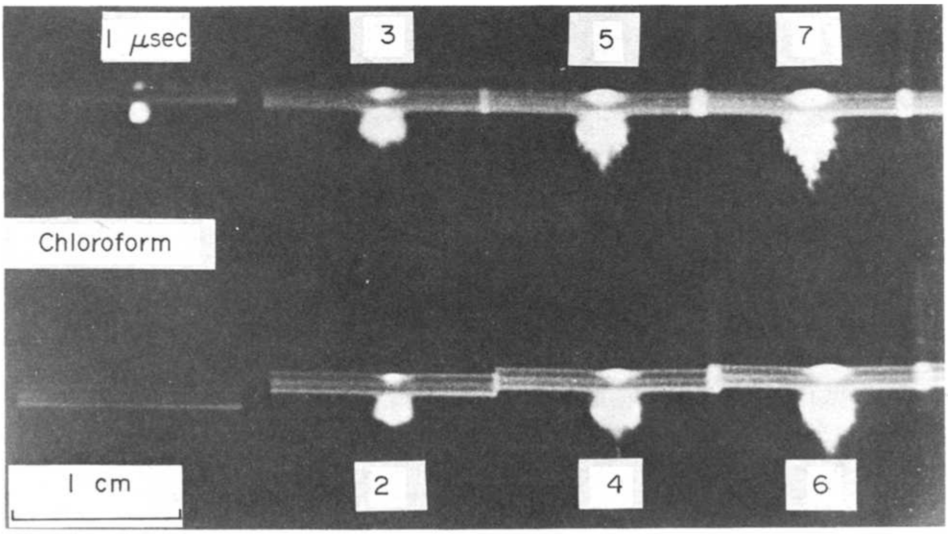


Fig. 4. Chloroform 10^6 frames s^{-1}.

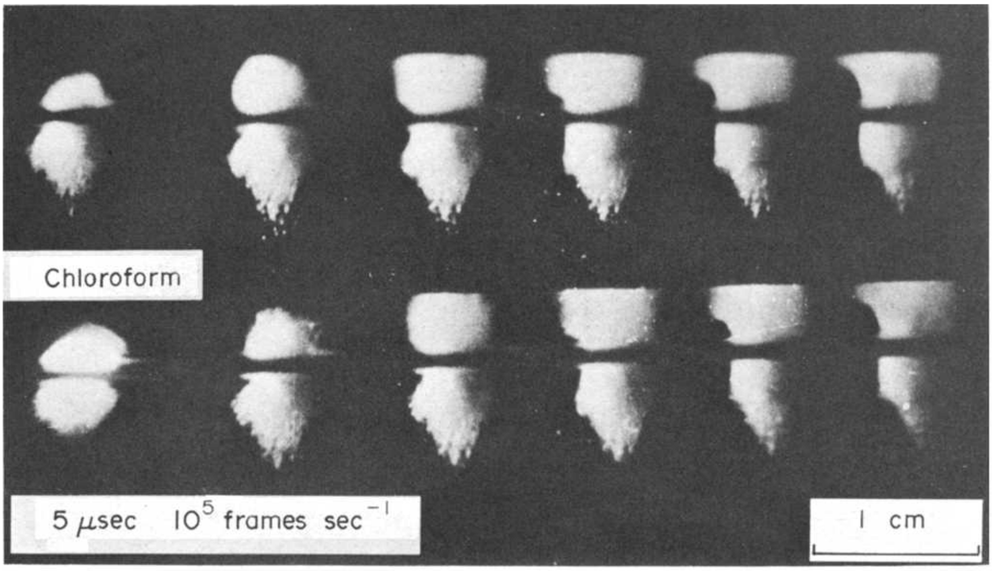


Fig. 5. Chloroform 10^5 frames s^{-1}.

small bubbles. The region of small bubbles grows with an initial velocity approximately equal to the sound speed in chloroform ($\sim$ 1000 m s^{-1}) but this front velocity falls to $\sim$ 600 m s^{-1} for the first few microseconds. Figure 5 shows the same event at the lower framing speed. Once again a dense vapour cloud is produced and the small bubbles in the liquid decrease after about 50 μs.

DISCUSSION

The bubble growth cannot be normal boiling because the thermal conductivity of the chloroform and the temperature gradient in the liquid are too low. Also the high absorption coefficient $\sim$20 cm^{-1} for chloroform means that the laser energy is quickly absorbed in the surface. Another mechanism must therefore be sought. The initiation of boiling in a liquid by the reduction of pressure, cavitation, is a well-known phenomena(5,6) and may be the explanation of the fast bubble growth reported here.

If a thin layer on the surface of a liquid is evaporated in a short time by the absorption of laser energy, the increase in pressure on the surface will give rise to a shock wave which will propagate into the liquid, Fig. 6. The pressure in the shock assuming some compression in the liquid is as shown. The rarefaction wave which forms to conserve mass in the shock may result in cavitation in the liquid. The formation of bubbles in the liquid will, therefore, proceed with a front velocity which is somewhat smaller than the shock velocity in the liquid.

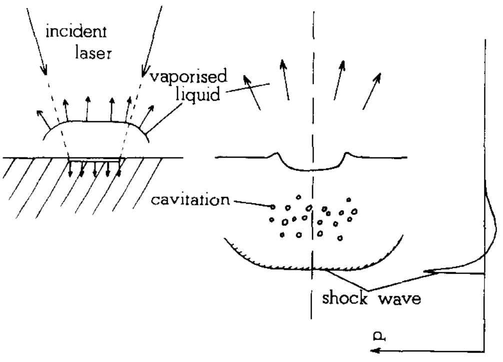


Fig. 6. Shock wave generation in the liquid.

The model which is tentatively proposed depends upon the presence of a shock wave in the liquid. Experiments are now in progress to visualise the shock wave in the liquid.

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