

PHOTOGRAPHIC OBSERVATIONS ON SHOCK WAVES IN LIQUIDS

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Summary

A simple method of photographing shock waves in liquids and of observing the absorption spectra of solutions under the extreme pressure and temperature conditions of shock waves is described. A thin layer of argon, compressed and heated by a shock wave, is used as a high intensity, short duration ($0.2 \mu\text{sec}$) flash source. The absorption spectra of the uranyl and neodymium ions are shown to be altered under these conditions.

I. INTRODUCTION

Shock waves generated in liquids by means of explosives can be utilized in experiments aimed at measuring the effects of very high pressures and temperatures. It is possible to make such measurements directly in the shock wave using apparatus which has a response time short compared with the duration of the shock wave (e.g. David and Hamann 1959a; or for general reviews Cook 1958; Sykes 1959). Alternatively, one can take direct photographs of the event and derive properties of the medium from the shape, position, density, etc. of the shock wave. The present paper describes two applications of the second technique.

II. PROCEDURE

Cole (1948) describes various methods of photographing shock waves in water and their application in the study of underwater detonations. The present work is on a much smaller scale than that described by Cole and in most experiments only about 60 g of explosive is used. Two small charges are mounted at right angles as shown in Figure 1. One charge launches a shock into the liquid contained in a small cell with plane windows. The second charge launches a shock wave into a thin layer of argon gas (1.5 mm thick) and, by compressing and heating the gas, provides the short duration ($0.2 \mu\text{sec}$) high intensity illumination required in order to "freeze" the motion of the shock front on the photograph (Winning and Edgerton 1952). The argon is contained in a Perspex cap slipped over the end of the explosive charge and is continuously blown into the cap during the experiment. The two main charges are connected by a bridge (David and Hamann 1960), cast of the same explosive, and are fired by a priming charge via this bridge. The flash is timed in relation to the compressive shock by placing the priming charge a suitable distance from the centre of the connecting bridge. This distance is calculated from the known detonation velocity of the explosive and the known propagation of the shock wave in water (David and Hamann 1959). By carefully shaping and assembling the explosive

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components and by making the two halves of the detonation path as far as possible symmetrical the flash can be timed to within ± 1 mm of travel of the shock wave.

The intensity of the flash is so great compared with the background that the camera shutter can be opened for the whole duration of the experiment, in the present work a shutter speed of 1/10 sec is used at an aperture of $f/36$. The flash-light contact in the camera shutter is used to close the detonating circuit.

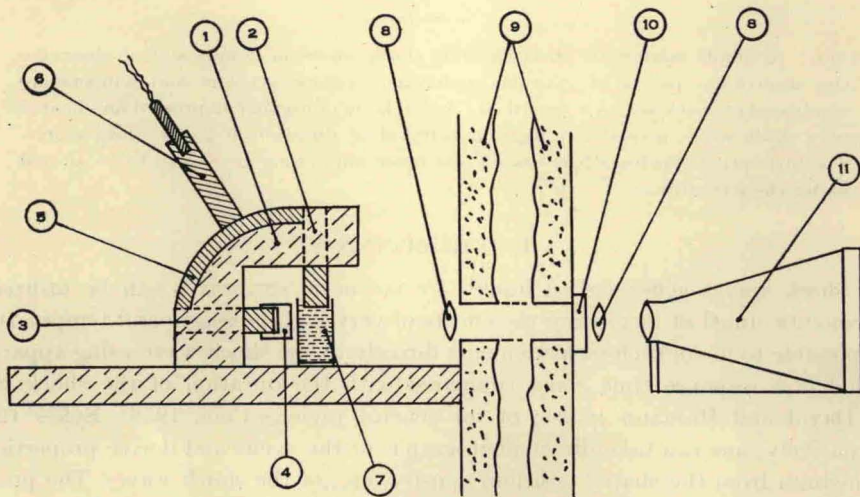


Fig. 1.—General arrangement.

1, Thick wooden block to hold compressive charge 2, which is connected by explosive bridge 5, to illuminating charge 3; 6, priming charge with detonator; 7, cell with windows of cellulose acetate film; 4, cap for argon gap; 8, lenses used in spectrographic work only; 9, concrete blast wall; 10, $\frac{3}{8}$ in. Perspex window; 11, camera.

The explosive charges are made of cast 60/40 RDX/TNT ("Composition B") and are 70 mm long with a diameter of 15 mm; the connecting bridge is cast of the same explosive and has a 1 cm square cross section.

III. RESULTS

(a) Photographs

Plate 1, Figure 1, shows a cell full of water before detonation. In this experiment two dummy electrodes were placed into the cell in order to observe their behaviour when a shock wave passes between them (David and Hamann 1959). The end of the compressive charge is seen above the electrodes and the argon cap behind them. The scale at the left shows lines 5 mm apart.

Plate 1, Figure 2, shows the shock wave just entered between the electrodes. The shock front appears as a dark line due to refraction and reflection at the refractive index discontinuity caused by it. A few millimetres behind the shock front one can see the cloud of opaque explosion products. The shock front in this case has travelled about 6 mm from the end of the compressive charge. The unchanged appearance of

the air bubble adhering to the lower part of one electrode shows that the liquid ahead of the shock is quite undisturbed. Plate 1, Figure 3, shows a shock wave which has travelled 10 mm into ethanol.

Plate 1, Figures 2 and 3, shows that the compressed liquid behind the shock front is transparent in both cases. This is an indication that freezing does not occur in spite of the high pressure in this region and is a confirmation of the finding of Walsh and Rice (1957) for water.

The actual pressure in the shock front cannot be determined directly but can be derived from the shock velocity and the free surface velocity in the shock. David and Hamann (1959) found in experiments in which similar explosive charges were used that the shock pressure at 5 mm distance from the end of the explosive was about 100,000 atm and the temperature 800 to 900° K. In those experiments the shock wave was however confined in a Polythene tube and since the shock propagation is very sensitive to the exact conditions surrounding the shock, these results are not directly applicable to the present experiments.

In the case of ethanol no shock velocity measurements under even approximately similar conditions are available for estimating the pressure. David and Hamann (1959, unpublished data) made some shock velocity measurements in methanol under the same conditions as in water and at 10 mm from the end of the explosive their results give a pressure of 64,000 atm in methanol compared with 68,000 in water. One would expect ethanol to give a similar pressure.

(b) Absorption Spectra

The photographic technique can also be used to investigate the absorption spectra of solutions under the extreme conditions obtained in shock waves. In order to do this the camera (11, see Fig. 1) is replaced by the entrance slit of the spectrograph and the lenses 8 are introduced in order to focus an image of the absorption cell on the slit.

The spectroscope used in the present work is a Hilger Constant Deviation Spectrograph which has an aperture of about $f/11$ and spreads the spectrum between 4000 and 6000 Å over 39 mm. Because of the strictly limited amount of light which can be obtained from an argon flash lasting 0.2 μ sec it was necessary to use a comparatively wide slit (0.05 mm) and very fast film (Ilford H.P.S.). Plate 2, Figures 1 and 2, shows the absorption spectra of 0.1M aqueous solutions of uranyl nitrate and neodymium chloride respectively. The four emission lines running across the spectrum are fortuitous and are due to the explosive flash other than that in the argon gap. They have been identified as the following lines: Na(D), 5890 Å (near red end of spectrum, not resolved); CaI, 4227 Å; CaII, 3968, 3933 Å (Petschek *et al.* 1955), and can serve as reference lines. In order to observe the solution both ahead of and behind the shock wave the full length (18 mm) of the spectroscope slit has to be used and this gives rise to the curved images on the photograph.

The lower part of Plate 2, Figure 1, shows the absorption bands in the blue which give uranyl nitrate solution its yellow colour. The upper portion shows the spectrum of the solution in the shocked condition. The absorption here is continuous

and extends into the green region of the spectrum. The pressure at the shock front in this photograph may be about 75,000 atm and the picture shows that a high pressure region extends behind the shock front for as far as is visible (5 mm) ahead of the opaque explosion products.

In Plate 2, Figure 2, the three equally spaced horizontal lines are due to 5 mm markers ruled on the front window of the absorption cell. The shock front is visible between the upper two markers. Near the bottom edge a mercury emission spectrum is superimposed. The wavelengths (in Å) marked along the top edge correspond to the maxima of the unperturbed absorption lines as determined on a microphotometer.

The absorption spectrum of an aqueous solution of neodymium chloride consists of a number of sharp lines and narrow bands and these are broadened and shifted to the red in the shocked solution. The pressure at the shock front in this case could be about 137,000 atm and the temperature about 1100°K. The temperature rise in the shock would alone account for the broadening of the absorption lines, but the red shift, amounting to between 20 and 30 cm^{-1} , can be attributed to the effect of pressure. This shift is very much smaller than those observed for transition metal complexes by Stephens and Drickamer (1959) at static pressures of up to 60,000 atm. The rare earth absorption which is due to excitation of well-embedded 4f electrons is presumably less affected by changes of environment caused by the high pressure than are the absorptions in the transition metals.

A detailed discussion of the spectroscopic results will be published later.

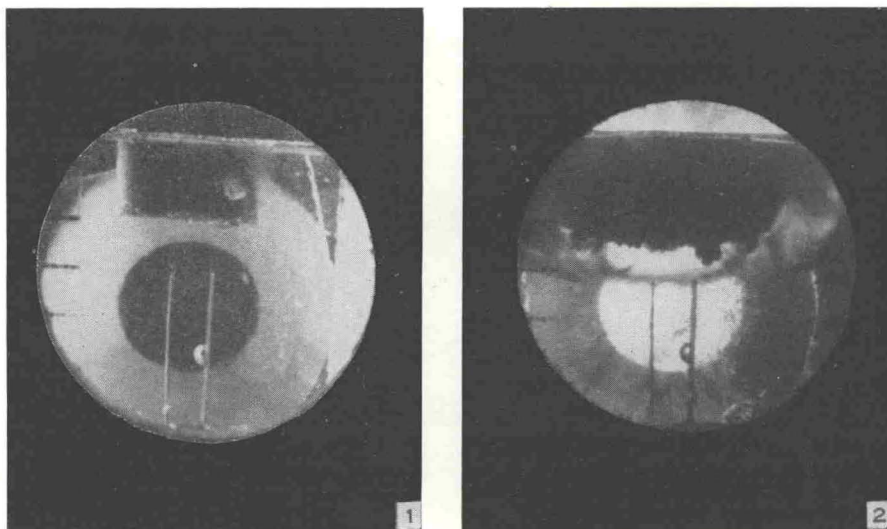
IV. ACKNOWLEDGMENTS

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A shock wave in water.

Fig. 1.—Arrangement as seen before detonation. Fig. 2.—During detonation.

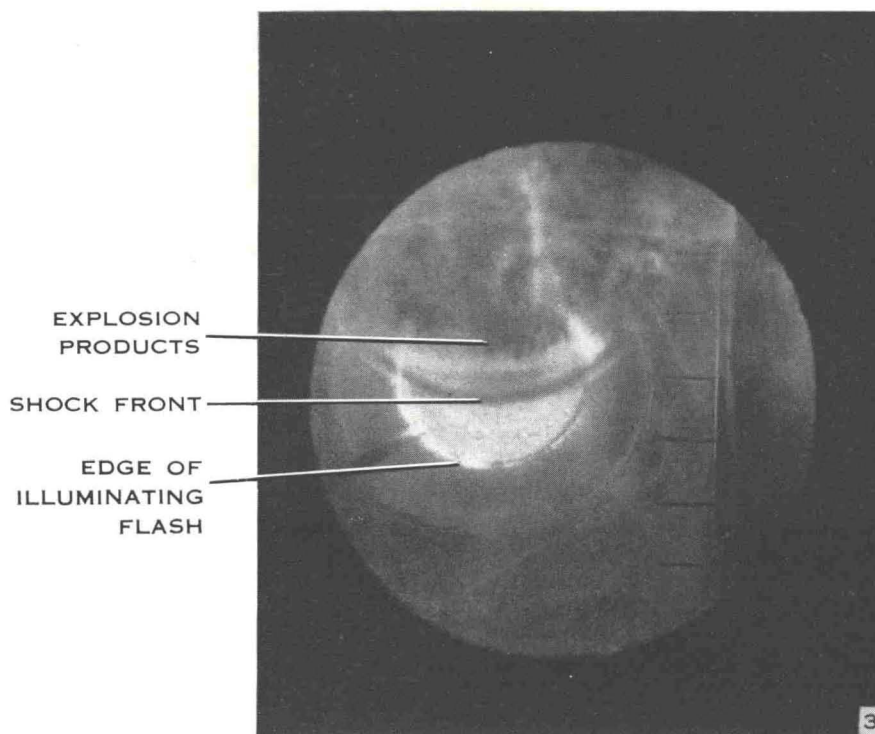


Fig. 3.—A shock wave in ethanol.

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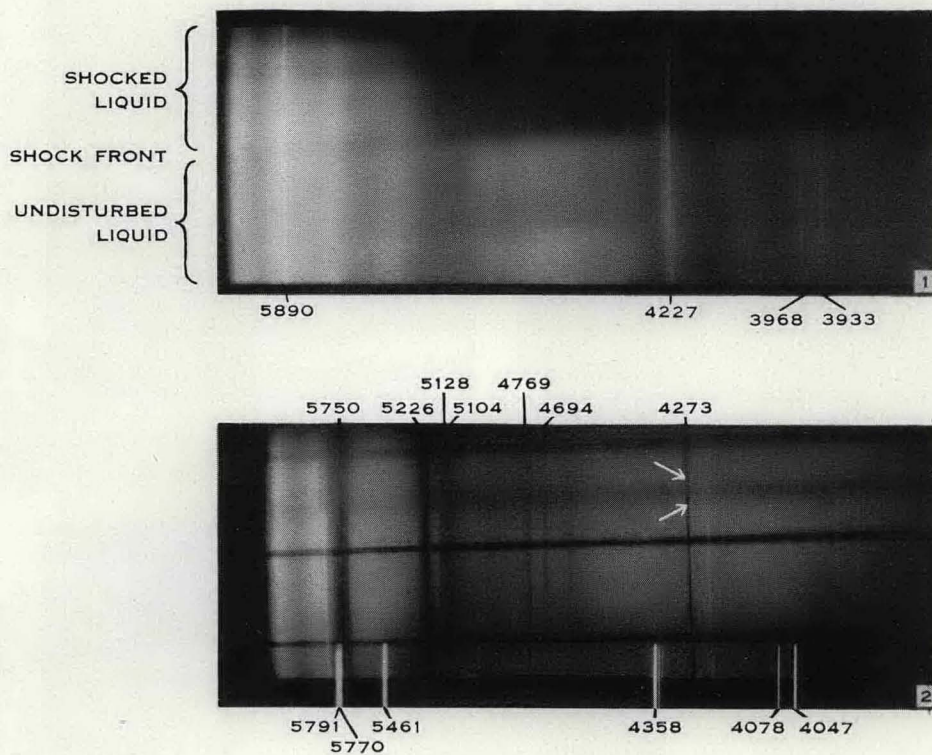


Fig. 1.—Absorption spectrum of 0.1M aqueous uranyl nitrate.

Fig. 2.—Absorption spectrum of 0.1M aqueous neodymium chloride.

The arrows point to the change in one of the absorption lines at the shock front.