INCREASING THE OPTICAL STRENGTH OF A LIQUID

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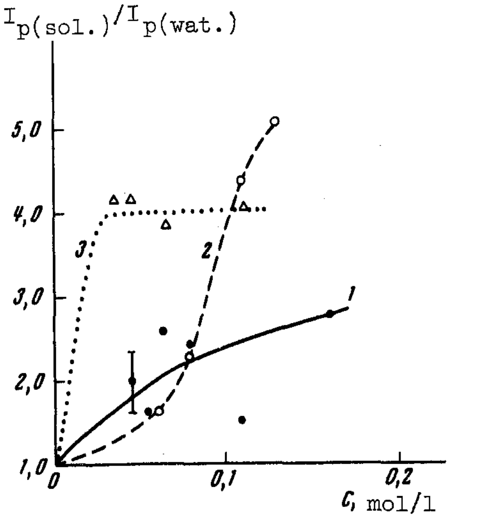
An increase in the threshold of optical breakdown of water by laser radiation was observed when salts of divalent copper were added to the water. It is shown that the increase of the threshold is connected with the structure of the complex produced by the copper ion with the water molecules.

We investigated the optical strength of a number of liquids, including aqueous solutions of transition-metal salts. The threshold of the optical breakdown of the liquid was determined from the minimum laser radiation power at which a light flash is produced inside the liquid. The experiments were performed with small drops (3 mm diam) of the investigated liquid. This made it possible, by additional focusing with the aid of the surface of the drop, to obtain the laser-pulse power density required to produce the breakdown, and to prevent breakdown on the surface of the cell. All the liquids were thoroughly cleaned of extraneous impurities by repeated filtering through a fine-pour ceramic filter. The linear absorption coefficient ($K_\lambda$) was measured with the aid of a laser at various pulse powers (below the threshold breakdown power). The laser was Q-switched ($\tau_p$ = 20 - 30 nsec) with $\lambda$ = 0.69 μ and $\lambda$ = 1.06 μ. The optical breakdown was detected by the appearance in the center of the drop of a single flash, which was viewed through a microscope. The threshold intensity was taken to be the average of 20 - 30 exposures.

It was shown for most investigated solutions that the solution breakdown threshold coincides with the breakdown threshold of the solvent. An entirely different picture was observed in aqueous solutions of copper salts. In this case the threshold of solution breakdown greatly exceeded the threshold for water when salt concentration was increased. Solutions of $CuSO_4$, $Cu(NO_3)_2$, and $CuCl_2$ in water were investigated. The results of the experiments are plotted in the figure. All the threshold intensities $I_p$ are referred to the intensity of the pure solvent. In the determination of the breakdown threshold we took into account the energy loss due to linear absorption in the drop, and the threshold breakdown power was taken to be

$$W = W_0 e^{-K_\lambda r_d}$$

where $W_0$ is the laser-pulse power at which breakdown was observed in 50% of the cases, and $r_d$ is the drop radius.




Solution breakdown threshold vs. salt concentration: 1) $CuSO_4$ in water, $\lambda$ = 1.06 μ; 2) $CuSO_4$ in water, $\lambda$ = 0.69 μ; 3) $Cu(NO_3)_2$ in water, $\lambda$ = 0.69 μ.

Additional measurements were made to determine the causes of the increased radiation strength of the solution. To check the influence of the anions $SO_4^{2-}$, $NO_3^-$, and $Cl^-$ on the change of the optical-breakdown threshold, we investigated the optical strength of aqueous solutions $Na_2SO_4$, $HNO_3$, HCl, and NaCl. The breakdown threshold of these solutions at different concentrations is equal to the threshold of distilled water. It follows therefore directly that the increased strength is due to the presence of the copper ion in the solution. However, the character of the influence of the copper ion on the breakdown mechanism in the solution can vary. The ions $Cl^-$ and $NO_3^-$ take little part in the formation of the copper complex in water, while the ion $SO_4^{2-}$ does not enter in the complex at all.

To verify the character of the influence of the copper ions on the optical breakdown threshold, we introduce ammonia into the aqueous solution of $CuSO_4$. Being a stronger ligand than water, the ammonia crowded out the water from the complex to form a new complex $Cu[(NH_3)_4(H_2O)_2]^{2+}$. Measurement of the breakdown threshold of this solution showed that the strengthening effect disappeared completely, and the breakdown threshold of the solution dropped to the value $I_p$ corresponding to pure water after addition of the ammonia. It was shown at the same time that addition of ammonia of the same concentration to pure water does not change the optical strength of the water. It could be assumed that the observed increase in the optical strength of the solutions was due to thermal defocusing connected with strong absorption of the laser radiation [2]. In all the investigated aqueous solutions of copper salts, the linear absorption coefficient is quite large and increases in proportion to the concentration in the investigated concentration range (for example, for $CuSO_4$ in water, $\kappa_{0.69} = \kappa_{1.06} \approx 12\ cm^{-1}mol^{-1}$). However, the breakdown threshold of $CuSO_4$ in water with ammonia added was the same at the laser wavelengths 1.06 and 0.69 μ, although the absorption band of such a complex (in comparison with $Cu[(H_2O)_6]^{2+}$) shifts to the short-wave region in such a way that the solution absorbs strongly at $\lambda = 0.69$ μ but not at $\lambda = 1.06$ μ. A solution of $CoCl_2$ in acetone, which absorbs at $\lambda = 0.69$ μ, likewise exhibited no change in the breakdown threshold in comparison with the solvent. Consequently, the linear absorption coefficients of the investigated liquids exerts no influence on the optical-breakdown threshold.

It follows from the results that the increase of the optical strength of the investigated solution, due to introduction of divalent copper, depends on the structure of the complex formed by the copper ions with the water molecules, since replacement of the water molecules by ammonia molecules, which changed the structure of the complex, caused the effect to vanish. It can be assumed that the increase of the optical-breakdown threshold is connected with the fact that the hydrated copper ions in the structure of the given complex hinder the development of the electron cascade by effectively capturing the free electrons or as a result of inelastic scattering. A similar process accompanying breakdown in gas was considered in [1].

It should be noted in conclusion that the observed increase in the strength of an optically transparent medium by introducing a small amount of additive can occur not only for liquids but also for solids. In this case the phenomenon can be used to obtain optically stronger materials.

[1] Ya.B. Zel'dovich and Yu.P. Raiser, Zh. Eksp. Teor. Fiz. 47, 1150 (1964) [Sov. Phys.-JETP 20, 772 (1965)].
[2] Engelhardt, Appl. Phys. Lett. 15, 7 (1969).