Self-illumination effect for acoustic waves in a liquid with gas bubbles

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Experimental observation of the effect of self-illumination of acoustic waves in a liquid with gas bubbles, involving a decrease of the coefficient of wave attenuation with increasing intensity, is reported. This effect is attributed to the grouping and coalescence of bubbles due to the action of the Bjerknes forces.

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The acoustic effects in a liquid with gas bubbles can be compared in physical complexity and diversity with the electromagnetic effects in the plasma. A resonant absorption of sound (analogous to the collisionless attenuation)[1] and production of acoustic solitons[2] are possible in this type of two-phase medium. The physics of the process are more complicated in those cases in which the acoustic field changes the state of the gaseous medium. The self-illumination effect described below is associated with such action.

The experiments were performed in a tank with dimensions $40\times40\times80$ cm^3. Figure 1 shows the schematic diagram of the experiment. An acoustic wave was pro-

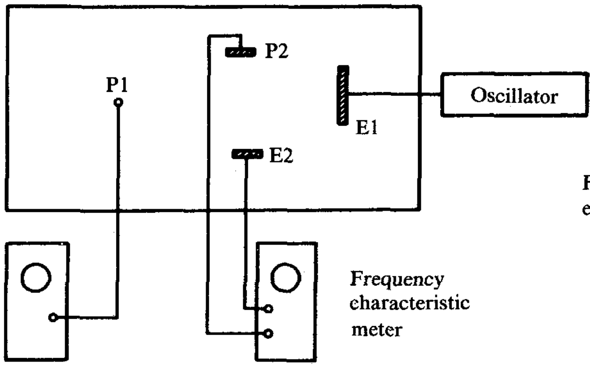

FIG. 1. Schematic diagram of the experiment.

duced by the piezoceramic emitter E1. The signal transmitted through the liquid was received by the piezoelectric transducer $P1$ located approximately 20 cm from the emitter. The bubbles were produced by electrolysis of water: a negative voltage of ~ 10 V was applied to the fine copper mesh located at the bottom of the tank. As a result of propagation of the sound through the bubble layer, the wave was strongly attenuated, but the attenuation coefficient decreased sharply when the intensity of the wave increased. In our experiments with an acoustic wave of 130-kHz frequency, the weak wave (the pressure amplitudes were $<10^3$ Pa), after passing through the layer, decreased in pressure more than 100-fold, but the stronger wave ($P \approx 3 \times 10^3$ Pa) was attenuated to one-third its amplitude. Figure 2 shows the dependence of the attenuation coefficient on the pressure amplitude in a wave generated by the emitter.

The transient properties of this effect are of interest. The attenuation coefficient decreases not immediately but several seconds after the increase of the acoustic field and increases in about 10 seconds after the field decreases.

To explain the mechanism for this effect, we investigated the influence of the acoustic wave on the size distribution of the bubbles. We measured the attentuation of the weak signal in the perpendicular direction to the propagation of the fundamental wave by using the emitter E2 and receiver P2 (Fig. 1). The frequency of the weak probing signal was varied in the frequency range of 90 kHz to 300 kHz (corresponding

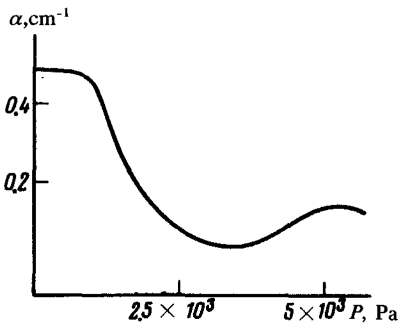

FIG. 2. Dependence of the attenuation coefficient on the amplitude of the acoustic wave.

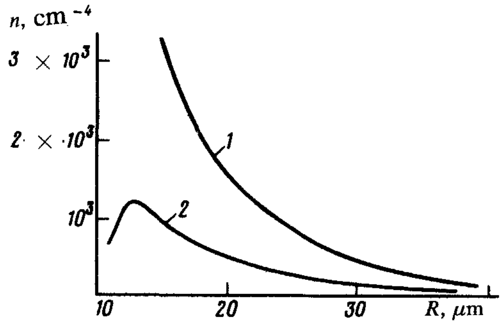

FIG. 3. Size distribution function of bubbles: curve 1—in the absence of perturbing acoustic wave; curve 2—in the case of self-illumination.
Oscillator

to the resonance radii of the bubbles of 11 to 36 μ). The size distribution function of bubbles $n(R)$ [$n(R)dR$-number of bubbles with radii of R to $R+dR$ per unit volume] is related to the attenuation coefficient α by the well-known relation[3]

$$n(R) = 1.38\cdot 10^{-3} R^{-3} \alpha, \tag{1}$$

where the attenuation coefficient is determined at a frequency corresponding to the resonant frequency for the bubble with radius R.

Figure 3 shows the $n(R)$ function in the absence of a strong perturbing wave (curve 1) and in the presence of an acoustic wave with the frequency of 130 kHz and pressure amplitude of 3.5×10^3 Pa (curve 2). The number of bubbles in the measured size range decreases sharply in the strong acoustic field.

This leads us to assume that the self-illumination effect is attributable to grouping and coalescence of the bubbles due to the Bjerknes force. This force, which occurrs between two vibrating bubbles, is defined in first approximation by the following expression[4]:

$$F = \frac{\rho < \dot{V}_1 \dot{V}_2 >}{4\pi l^2}, \tag{2}$$

where l is the distance between the bubbles, and $\dot{V}_1$ is the time derivative of the bubble volume. The coalescence time of two bubbles under the action of the Bjerknes force, which was estimated according to the formulas in Ref. 4, at the acoustic wave amplitude of 10^3 Pa is equal to $\sim$2 seconds for two bubbles with radii of 10 and 20 μ that are spaced 1 cm apart. This time is in good agreement with the measured time of the self-illumination.

The delay of the inverse attenuation after the acoustic field is turned off is evidently attributable to the time required for the emersion of bubbles and for the filling of the region occupied by the wave with small resonant bubbles.

We note that the coalescence of bubbles to the visible size ($R > 40\ \mu$) was visually observed in the experiment. It is interesting to note that the formation of clusters comprised of ten or more bubbles was observed in a number of cases. Upon discharge from the beam, such clusters broke down again into individual bubbles.

The plasma analog of the observed self-illumination effect is the effect of self-illumination of the Langmuir waves, which influences the distribution function.[5]

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