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DYNAMICS OF A VAPOR BUBBLE IN HELIUM AND HYDROGEN ULTRASONIC CHAMBERS

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SUMMARY [*]

The results are presented of experimental and theoretical investigations of track formation in a liquid-hydrogen bubble chamber in the ultrasonic field. Different physical phenomena are considered characterising the dynamics of the vapor pockets.

The dynamics of the nucleating bubble is studied: cavitation and diffusion thresholds are determined as well as the dependence on the initial phase and surface tension.

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*) The above summary in English was provided by the authors, L.G. Tkachev and V.D. Shestakov.

Results of experiments conducted in ultrasonic bubble chambers filled with helium (1-2) and hydrogen (3-4) have shown that the embryonic bubble, initiated by a charged particle, grows to visible size ($\simeq 10^{-2}$ cm) during 60 - 100 periods of the ultrasonic field.

The studies (5-7) explored theoretically the dynamics of a vapor bubble in liquid hydrogen. Theoretical calculations agree with experimental data concerning the behavior of a bubble in an ordinary bubble chamber (8). As far as ultrasonic bubble chambers are concerned, it was shown that due to rectified heat diffusion the pulsating bubble grows to asymptotic size in the liquid which has not been overheated, and is determined by the amplitude P_1, by the frequency f of the ultrasonic field, as well as by the static pressure in the liquid P and its temperature T_∞. Quantitative experimental data concerning the size of a bubble in ultrasonic chambers is now available.

The first part of the present communication discusses the results of a numerical solution of the system of equations (formulated in papers (5-7)) for initial and boundary conditions, corresponding to those thermodynamic and acoustic parameters which were obtained in experiments (1, 3). The second part examines the dynamics of the embryonic bubble in liquid hydrogen.

I

As in papers (5-7), it is assumed that the system of bubble-liquid is spherical and that the vapor in the bubble is homogeneous and is in a thermodynamic equilibrium with the surface layer of the liquid. The assumption that the vapor is homogeneous means that its parameters depend only upon time and are independent of the space coordinates.

Solid lines in figs. 1 and 2 indicate the theoretical dependence of the mean bubble radius for each period upon time in hydrogen and helium; given also is its experimental value, obtained in an ultrasonic bubble chamber at the end of $\approx$ 60 cycles.

Several reasons exist for the discrepancy between theory and experiment.

First of all, theoretical curves relate to an individual bubble, while experimental data concerning size can be appropriate for a cluster of bubbles, resulting from a fragmentation of the initial bubble during its pulsation in the ultrasonic field.

Second, the above description of the dynamics of bubbles is correct only as long as the vapor in the bubble can be considered homogeneous, whereas this in turn depends upon the character of the thermal processes in the vapor. As is known, the means for the transfer of heat in a continuum is thermal conductivity and convection. If within the bubble only thermal conductivity takes place, then the hypothesis that the vapor is homogeneous is correct, when the following relation

$$R \le \sqrt{2 D' \tau} = l_{diff} \tag{1}$$

is fulfilled, where R - bubble radius, l_{diff} - the diffusion length, D' - thermal diffusivity of vapor, τ - time, during which an essential temperature change in the bubble takes place, equal in the order of magnitude to a period of the ultrasonic field. If in addition to thermal conductivity, there is also convection (in proportion to the growth of the bubble), which facilitates the decrease of non-homogeneity, then one has the possibility of examining within the frame of the above approach larger homogeneous bubbles than those which are determined by the relation (1). It is difficult to calculate theoretically the role of convection of a bubble. From a comparison of theoretical and experimental data we can obtain here indirect indication concerning the behavior of bubbles in an ultrasonic field, since their size

(10^{-2} cm), as observed in ultrasonic chambers, as a rule exceeds the diffusion length in the vapor phase. One of the interpretations for the existing discrepancy between theory and experiment can be the hypothesis that convection does not lead to any significant increase in the speed of heat exchange within the large bubble. Therefore, in examining the dynamics of large bubbles in an ultrasonic field, one must take into account the non-homogeneity of the vapor within the bubble.

Thirdly, there can be microflow in the liquid around the bubble (9) pulsating on account of ultrasound, which basically must increase the rectified heat diffusion, which leads to the growth of the vapor bubble. Theoretical treatment does not consider the influence of microflow.

Microflow increases the transfer of heat in the liquid by approximately ten times (9). As a consequence of the non-homogeneity of the vapor, only that part of the vapor volume participates in the heat and mass exchange with the surrounding liquid, which comprises of the total volume the fraction $l_{diff} / R \approx (10^{-1} \div 10^{-2})$. The role of the two factors can be evaluated by substituting for the coefficient of thermal conductivity of the liquid K the value $K_{eff} = (10 \div 100) K$. The corresponding curves are indicated by dashed lines in figs. 1 and 2. From the nature of the curves it is seen that the given rough evaluation allows for the description of the existing experimental data. From this follows, that the non-homogeneity of the bubble and the existence of microflows in the liquid exert fundamental influence upon the dynamics of asymptotic vapor bubbles and must be more thoroughly examined.

However, more detailed experimental information about the growth of the bubble from the embryonic to asymptotic size is necessary for a more precise explanation concerning the role of microflows and the non-uniformity of the bubble.

II

It was shown in papers $^{(5, 6)}$ that due to rectified heat diffusion the radius of a bubble increases with pulsations. However, there exists such a threshold value for the amplitude P_{diff}, that when $P_1 < P_{diff}$ the amount of rectified diffusion present is insufficient, and the initial bubble collapses. With amplitudes $P_1 > P_{cav}$, where P_{cav} - cavitation threshold, the pulsations of the bubble have such a large amplitude, that it collapses due to surface tension during the phase of compression.

In principle, an ultrasonic bubble chamber can be realized only when $P_{diff} < P_{cav}$ for the entire range of bubble radii, from the embryonic to the visible size. For liquid hydrogen ($T_\infty = 27$ K, $P_o = 5.0$ bar, $R(0) = 2 \cdot 10^{-6}$ cm) P_{diff} and P_{cav} were numerically calculated for the frequencies from 30 to 400 kc/s. The values for the diffusion and cavitation thresholds are constant: $P_{diff} = 1.8$ bar, $P_{cav} = 4.4$ bar. Dependence upon frequency is absent and can be explained by the fact that the frequency of the embryo's own pulsations lies far beyond the boundaries of the range examined. When $P_{diff} < P_1 < P_{cav}$, the embryonic bubble grows even up to asymptotic sizes, that is, for $R > 2 \cdot 10^{-6}$ cm the interval of allowed values for P_1 can only increase.

Differing from ordinary bubble chambers, where sensitivity to ionizing particles is reached simultaneously in the entire volume, in ultrasonic chambers the liquid is sensitive only in those regions, which are characterized by determined phase values of the ultrasonic wave; therefore, in ultrasonic chambers the tracks are broken. It is of interest to examine the behavior of embryonic bubbles, formed during different initial phases.

Fig. 3 shows the dependency of the radius for the embryonic bubble upon time during different initial phases of the ultrasonic field ($T_\infty = 24.6$ K, $P_o = 3.4$ bar, $P_1 = 2.6$ bar, $f = 300$ kc/s).

Apparently, the allowed phase range comprises 0.8 ÷ 2.0 rad, corresponding to the size of the tracks observed in experiment (3). It can also be seen that for favorable phase values the embryonic bubble grows to 10^{-4} cm during a small part of the period; during subsequent pulsations it does not decrease below this size. Therefore, the values for P_{cav} and P_{diff} determined above factually depend upon the behavior of bubbles having a radius of $R \approx 10^{-4}$ cm, although the interval of favorable phases for them will be different.

It is normal to expect the behavior of the embryonic bubble to be essentially dependent upon surface tension. In order to clarify the latter's role, it is appropriate to examine the evolution of the embryo in an overheated liquid, without the complicating influence of the ultrasonic field. Fig. 4 depicts the dependencies of the radius of the bubble upon time, where $R(0) = 2 \cdot 10^{-6}$ cm, $P_o = 0.8$ bar, $T_\infty = 24.6$ K, with the dotted curve corresponding to the case $\sigma = 0$. It is seen, that with the growth of the bubble both curves approach one and the same asymptote, which determines the bubble's behavior in accordance with formula $R \approx \sqrt{t}$. Existing experimental data (10) confirm this dependency for $R \gtrsim 5 \cdot 10^{-3}$ cm. For small bubble radii the influence of surface terms leads to a decrease of the effective overheating of the liquid and, consequently, to a decrease in the growth rate of the bubble.

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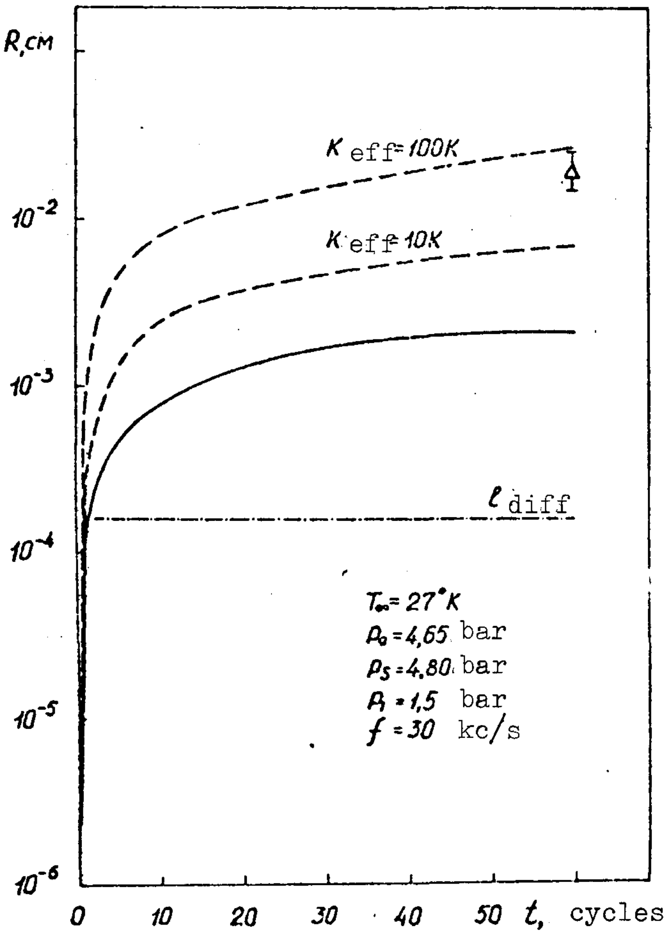

Fig. 1 The dependence of the mean bubble radius upon time in an ultrasonic bubble chamber filled with liquid hydrogen.

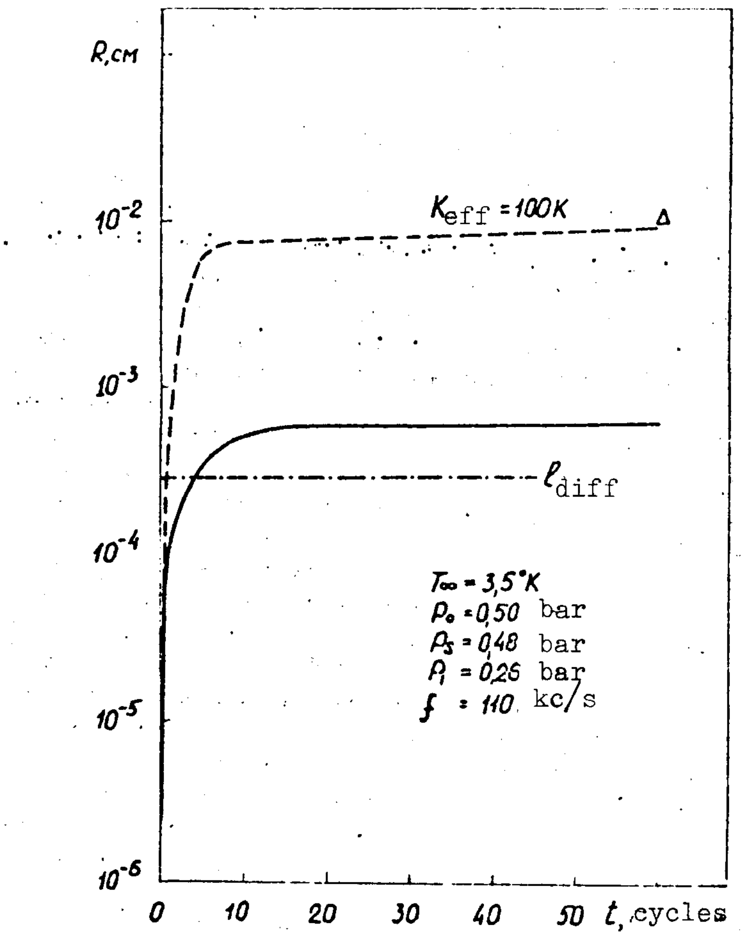

Fig. 2 The dependence of the mean bubble radius upon time in an ultrasonic bubble chamber filled with liquid helium.

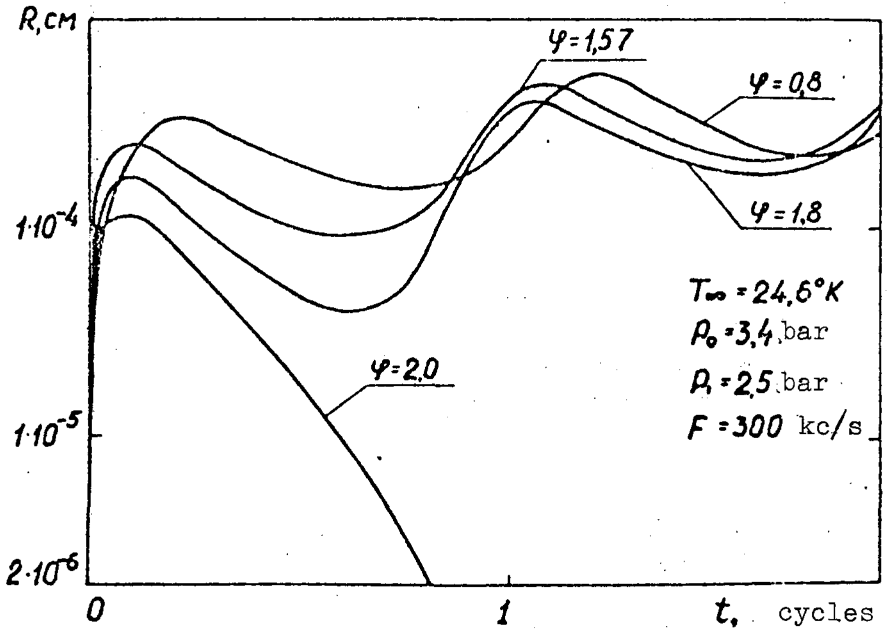

Fig. 3 The dependence of the radius of the embryonic bubble upon time during different phases of the ultrasonic field.

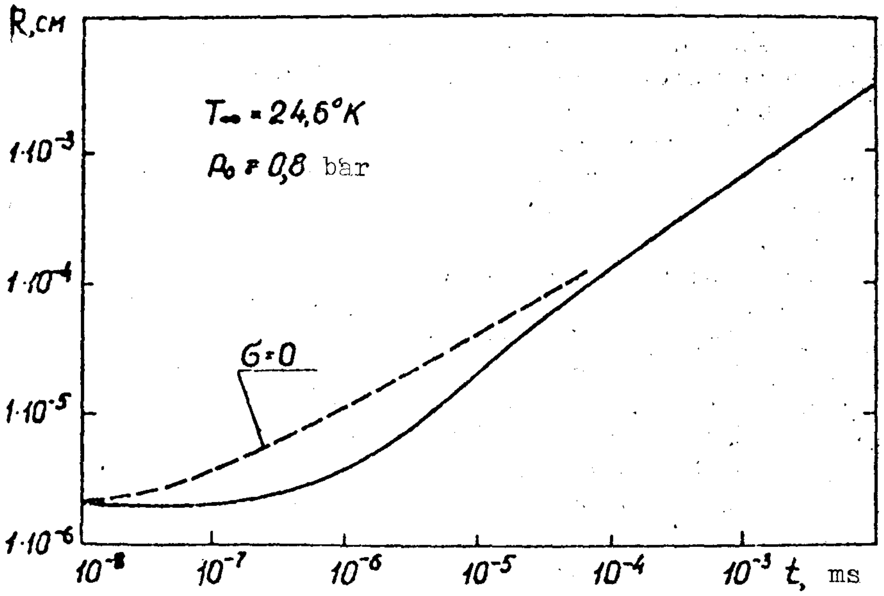

Fig. 4 The dependencies of the embryonic bubble radius upon time: the solid line takes into account surface tension; the dashed line does not consider surface tension ($\sigma = 0$).