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STUDY OF TRACK FORMATION OF IONIZING PARTICLES IN AN ULTRASONIC FIELD IN A LIQUID HYDROGEN BUBBLE CHAMBER

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ABSTRACT

Results from an experimental investigation on track formation of ionizing particles in a liquid hydrogen bubble chamber are presented. Overheating of the working liquid was performed by joint action of a system of ultrasonic emitters, exciting standing waves with a frequency of 30kHz, and an ordinary expansion system. For bubbles, which are related to tracks of ionizing particles the dependence of their size on the ultrasonic pressure amplitude and on the static pressure in the liquid is obtained. When strong ultrasonic fields are excited in liquid hydrogen parasitic boiling (cavitation) is found to appear on the emitter surface, which limits the ultrasonic pressure amplitude and affects the track formation of ionizing particles. The possibilities for the creation of an ultrasonic bubble chamber and its application in high-energy physics are discussed.

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The creation of an ultrasonic hydrogen bubble chamber depends on the solution of a complicated technical problem. The reason is that, for the formation of tracks of ionizing particles in liquid hydrogen, strong ultrasonic pressure amplitudes must be achieved in a medium with relatively low (acoustic) wave impedence. This leads to the necessity of emitting ultrasound of sufficiently high power (~50 watt/cm^2) into liquid hydrogen.

In liquid helium, which has more favourable thermodynamical characteristics for track formation, the probelm is substantially simplified. In this case the easily obtainable ultrasound intensity of ~1 watt/cm^2 is needed. Therefore the construction of a helium ultrasonic bubble chamber was successful with the use of simple disc elements of piezoceramic PZT-4 (lead-zitconate-titanate) as ultrasound emitters 1).

It is obvious that at this stage the creation of a liquid hydrogen USBC is feasable using a focused ultrasound system, which permits to obtain a sufficiently high ultrasound intensity in some part of the working volume of the chamber. This direction was indicated in the work 2) in which for the first time tracks of ionizing particles were observed in a liquid hydrogen USBC using an ultrasound emitter in combination with a mechanical expansion system. This direction may prove useful in those cases, where the USBC may be used as rapid-cycling target detector and where there is no strong request for homogeneity of the tracks and an effective use of the whole working volume.

However, high quality homogeneous tracks may probably be obtained only in a field of plane ultrasound waves of sufficiently high frequency. The simplest way to create such fields is based on the use of plane disc emitters.

Because the efficiency of such emitters at low temperatures had not been studied sufficiently, we carried out tests on some types of plane piezoceramic elements of lead-zirconate-titanate (ZTS) at liquid nitrogen and hydrogen temperatures. It was found, that because of mechanical stresses, related to the piezo-effect and the development of heat in the ceramic the half-wave piezoceramic elements usually break at levels of ultrasound intensity well below that required for the creation of the necessary pressure drop.

A similar result was already obtained in the work 3), where piezoceramics of the type PZT-4 were used.

In connection with the difficulties pointed out, we examined the possibility of applying new ideas in the construction of ultrasound emitters. For this we made best use of the experience in the construction of compound ultrasound systems, developed for operation in ordinary liquids 4).

In the present work we present the results on the investigation of track formation of ionizing particles in a liquid hydrogen bubble chamber under the influence of an ultrasound field, excited by compound ultrasound emitters, especially developed for use in cryogenic liquids. The investigation was carried out, as in work 2), with a 25cm liquid hydrogen bubble chamber 5), set at a temperature of $27^{o}K$, which corresponds to a vapour pressure of roughly $P_n = 4.8$ at. The static pressure P'_o in the chamber was set at 5.2 at.

The block-diagram of the experimental apparatus is shown in Fig.1. The distance between the emitting surfaces was adjusted in advance in the mounting to about 58 mm, which corresponds to two ultrasound wave lengths at the resonance frequency of 30 kHz at a temperature of $27^{o}K$. Thereby 5 zones of sensitivity are formed in the working volume of the bubble chamber between the emitters (see Fig.1). The accurate adjustment of the emitters was carried out by remote control under working conditions with the help of a mechanical system, which allowed to move one emitter up to ±10 mm in axial direction. Visual observation of the behaviour of the liquid in the regime of continuous emission of ultrasound at reduced intensity allowed to choose very accurately the optimum efficiency of the emitters, when a standing wave field was formed between them.

The construction of the emitters is clear from Fig.2. Piezoceramic discs of ZTS ceramic of 50 mm diameter and 5 mm thickness were used. In the chosen construction they were assembled between metallic discs and an outer cylindrical body with plane surfaces. To increase the mechanical strength of the emitters and the lifetime of the piezoceramic elements, they were compressed hydraulically with 200 kg/cm^2 and in addition fixed by a nut. The use of metallic elements for the emitter construction with a thermal expansion coefficient close to that of the piezoceramic (titanium alloys) was successful as it maintained the mounting pressure down to low temperatures. A layer of indium was introduced between the piezoceramic and the metal to ensure acoustic contact.

The emitting wall had a varying cross-section which allowed to increase the emitting surface and with it the efficiency of the emitter. Besides this, some increase of the efficiency was achieved by removing the piezoceramic elements from the central part of the emitter, where the deformations during vibration and the binding of internal losses are maximum.

A general view of the ultrasound system, mounted in the flange of the hydrogen USBC, is shown in Fig.3.

The experimental investigation on the formation of tracks of ionizing particles under the influence of an ultrasound field was carried out in the following manner, as in the earlier work [2). Once the working volume was brought into optimum conditions for sensitivity, the overheating being produced by the mechanical expansion system was reduced in steps. Conditions were reached under which sensitivity of the chamber to ionizing radiation practically disappeared. Then the chamber sensitivity was restored by introducing pulses of the ultrasound field. To produce ionising particle tracks a beam of π^-- mesons of 340 MeV from the synchrocyclotron of the Laboratory of Nuclear Problems JINR was used. The moment at which particles passed through the working volume was exactly synchronized with the switching of the mechanical expansion system as well as with the emission of the ultrasound pulse and the illumination flash for the chamber. Tracks of ionizing particles in the bubble chamber were photographed by a stereo camera, but visual observation is done with the help of a television screen.

Fig. 7 shows the change of pressure in the bubble chamber, caused by the expansion system and the ultrasound emitters. In the figure are indicated : the beginning t_o of the excitation of the ultrasound pulse, the beginning t_1 of the ionizing particle beam from the accelerator and the time t_2 for taking the track photos. The ultrasound pulse of 10 ms duration is applied approximately 5 ms before the arrival of the ionizing particles. The spill of the particle beam from the accelerator was $\sim$0.3 ms and equals about 10 ultrasound periods at the frequency of 30kHz. The time interval $t_2 - t_1$ between picture taking and arrival of the particle beam was $\sim$2 ms, which equals about 60 ultrasound periods. In the figure the following terms are introduced: P'_o = the initial static pressure, P_o = lowest pressure level achieved by the expansion system, P_π = saturated vapour pressure of liquid hydrogen, P_2 = threshold of sensitivity for ionizing radiation, P_m = ultrasound pressure amplitude, P_H = lowest pressure realized in the bubble chamber.

It should be noted, that tracks in an ultrasonic chamber grow to visible size and may be registered only in such areas, where during the traversal of the ionizing particles the pressure in the ultrasound field is negative and not above the pressure P_2. Thus, at each traversal of the working volume the track initiated by a particle appears broken up in space, the distance between the seperate parts of the track being equal to one ultrasound wavelength.

In Fig.5 a typical photo is shown of a track in the ultrasonic hydrogen bubble chamber, achieved by the combined action of ultrasound and an ordinary expansion system. The latter ensured an expansion step of ~0.3% in the liquid, which corresponds to a decrease of about 0.7 at in the static pressure in the chamber. The voltage on the emitter was 1 KV. Then the pressure amplitude P_m of the ultrasound was ~1.5 at. For reasons of clearness the contours of the emitter in the dark field have been reproduced on the photo as white lines.

To investigate the threshold condition for the formation of tracks in an ultrasound field the expansion of the liquid due to the expansion system was reduced stepwise, and the voltage on the ultrasound emitter increased at each value. Figs. 6 and 7 represent photos of tracks, which were obtained at various voltages on the emitter and at initial expansions of about 0.24 and 0.18%.

It should be noted, that in the last case the action of the mechanical expansion system hardly compensates the overpressure. Thus, the pressure in the chamber was equal to the saturated vapour pressure when the ultrasound was switched on. Nevertheless the particle tracks are well visible on the photos at some values of the emitter voltage. It is also characteristic, that an increase in the electric power input leads to the development of parasitic boiling (cavitation) on the surface of the emitter, and finally to the complete suppression of particle tracks (photo on the right of Fig.7).

It is known [7)], that cavitation in liquids causes a drop in the radiation resistance, a decrease of the emitter efficiency and of the pressure in the ultrasound field. Fig. 8 shows the dependance of the pressure amplitude in the antinodes of the ultrasound field on the voltage. Measurements were carried out with a miniature piezoceramic receiver (see Fig.1,10) positioned in the middle between the emitters. It can be seen, that after some values the linear relationship between pressure and voltage breaks down. The maximum pressure amplitude, approximately 1.75 at, is observed at $U = 1.2$ kV. Further increase of the voltage leads to a decrease of the pressure in the ultrasound field.

A more complete description of the influence of cavitation on the conditions for track formation in an ultrasound field is given by measurements of the transverse dimension of dense tracks, of the diameter of single bubbles from which tracks are formed and of the diameter of cavitation holes formed on the emitter surface. Measurements on the film were carried out with a microscope. The dependance of the above mentioned quantities on the emitter voltage is represented in Fig.9. In the treatment of the data it was assumed that the measured dimensions of the bubbles and tracks on the photos correspond to the maximum values of the bubbles pulsating in the ultrasound field. The scattering of the maximum diameter ($2R_m$) as shown in the figure may be due to different initial conditions for the bubble growth. This is related to the arrival of the particle beam at different phases of the ultrasound field as well as to the different number of periods for bubble growth, because the spill of the particle beam is comparable to the time between particle traversal and picture taking. Because of photographic effects the imaging of the bubble on the film does not give a correct representation of the real dimensions. Therefore the determination of the bubble size was carried out by comparison with bubbles observed in the imaging system which were obtained photographically under the same conditions of specially calibrated bubble tracks 8).

The results, represented in Fig.9 probably indicate that with increasing voltage the dimensions of dense tracks and that of single track bubbles grow only to a fixed limit, whereas the size of bubbles from parasitic boiling (cavitation) on the emitter surface continues to grow.

From these results, represented in Figs. 8 and 9, one may deduce the dependance of the size of dense tracks and single track bubbles of ionizing particles on the ultrasound pressure amplitude and on the pressure in the chamber (Fig. 10). The obtained results allow a quantitative description of the track (bubble) dynamics in the ultrasound field in liquid hydrogen. This is certainly of interest for the further development of theoretical and pratical work on liquid hydrogen bubble chambers.

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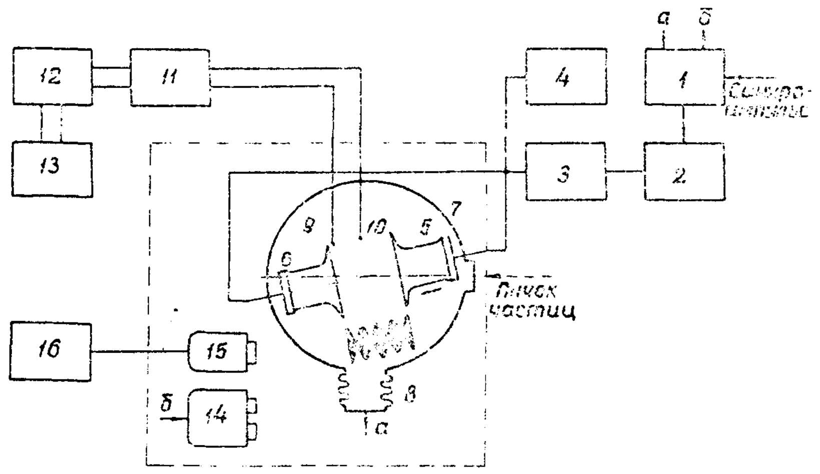


Fig. 1 Block-diagram of the experimental apparatus.

1 : Synchronization box; 2 : Generator for the oscillation pulse; 3 : Power amplifier; 4 : pulse-voltmeter; 5 and 6 : Ultrasound emitters; 7 : Liquid hydrogen bubble chamber; 8 : Mechanical expansion system; 9 and 10 : Miniature ultrasound probe; 11 : Amplifiers; 12 : Oscilloscope; 13 : Tube voltmeter; 14 : Stereo-camera; 15 : Television camera; 16 : Television receiver.

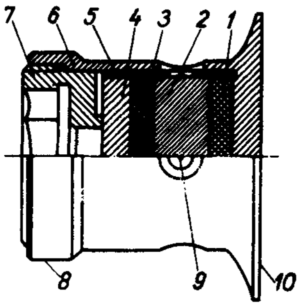


Fig. 2 Compound ultrasound emitter.

1 and 3 : Piezoceramic elements; 2 and 4 : Metallic discs; 5 : Teflon isolator; 6 : emitter housing; 7 : Tightening nut; 8 : Point for supporting; 9 : Clamp; 10 : Emitting surface.

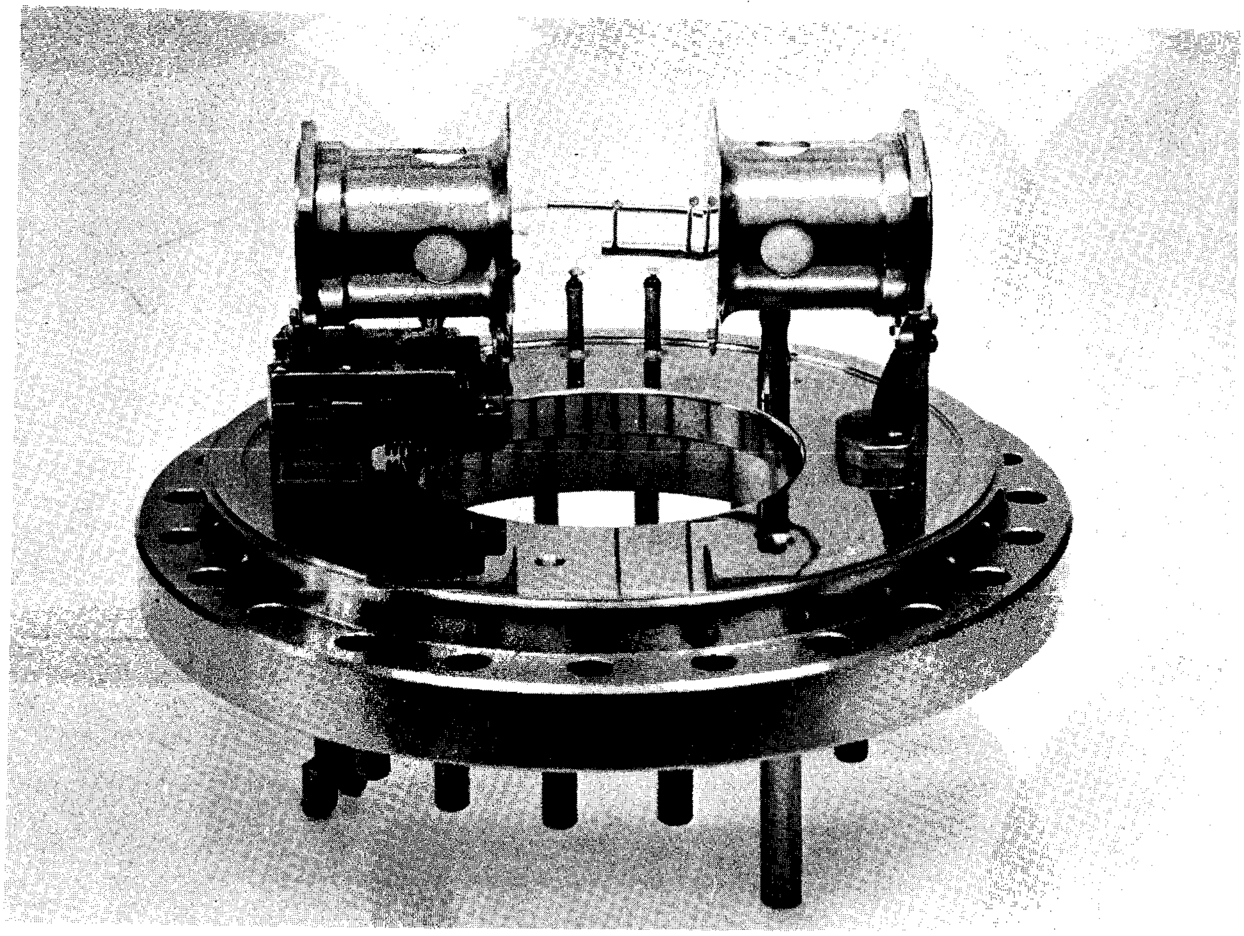


Fig. 3 General view of the ultrasound system on a flange of the bubble chamber.

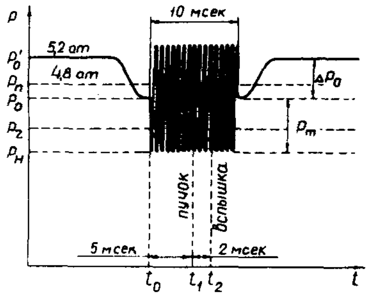


Fig. 4 Diagram of the time dependence of the pressure in a bubble chamber under the condition of combined action of ultrasound and mechanical expansion system.

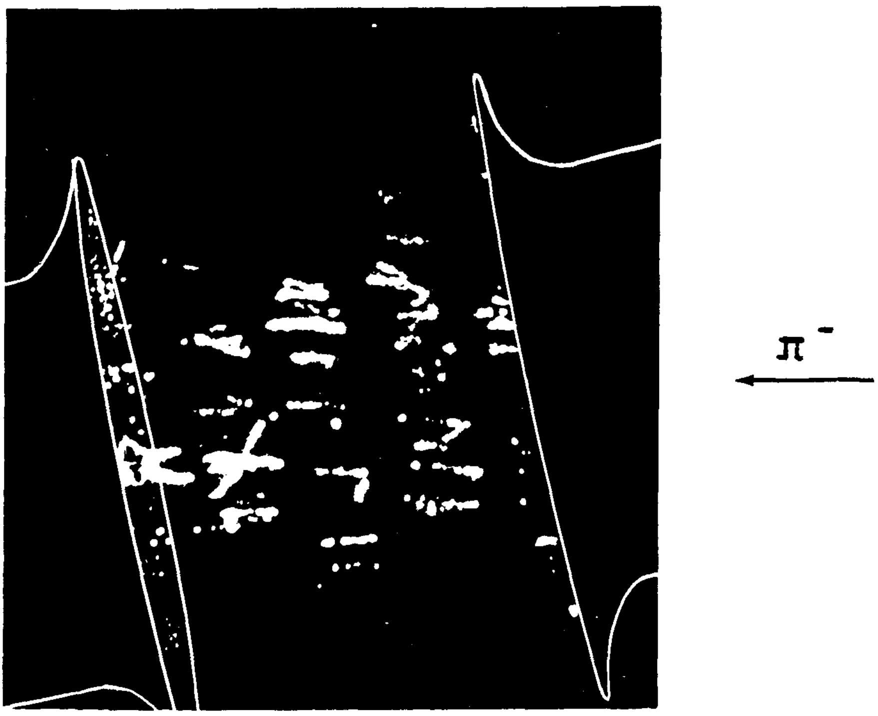
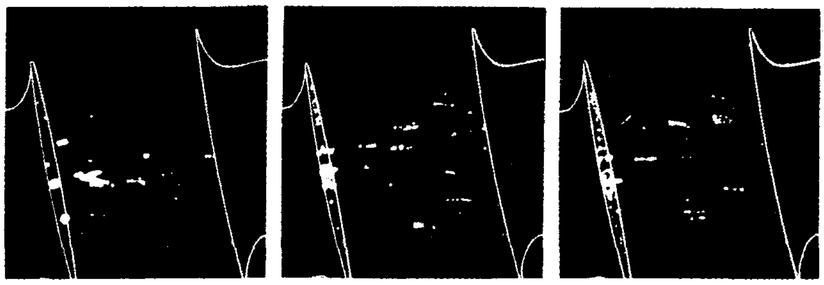
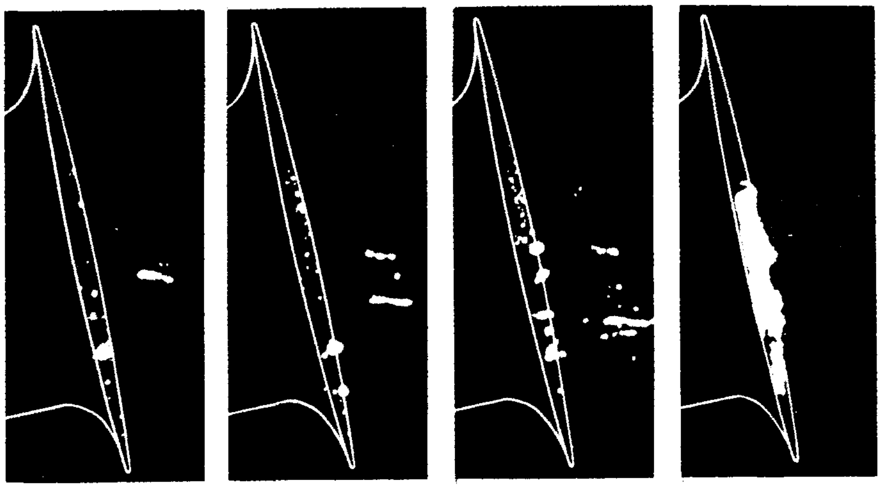


Fig. 5 Tracks of negative pions of 340 MeV in a standing wave ultrasound field in the liquid hydrogen bubble chamber ($\Delta V/V = 3 \times 10^{-3}$; $P_o = 4.5$ at; $U = 1.0$ kV; $P_m = 1.5$ at).



V = 1 kV V = 1.2 kV V = 1.4 kV

Fig. 6 Tracks of negative pions in the ultrasound field of the liquid hydrogen chamber at various voltages on the ultrasound emitter ($\Delta V/V = 2.4 \times 10^{-3}$; $P_o = 4.65$ at).



V = 1.4 kV V = 1.5 kV V = 1.6 kV V = 2 kV

Fig. 7 Parasitic boiling (cavitation) on the surface of the ultrasound emitter in liquid hydrogen at various voltages ($\Delta V/V = 1.8 \times 10^{-3}$; $P_o = 4.8$ at).

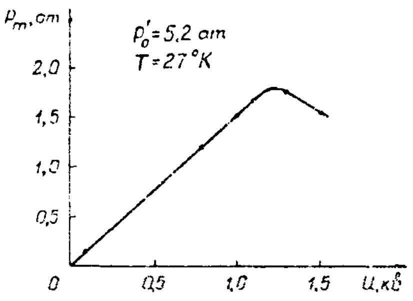


Fig. 8 Dependence of the ultrasound pressure amplitude on the emitter voltage.

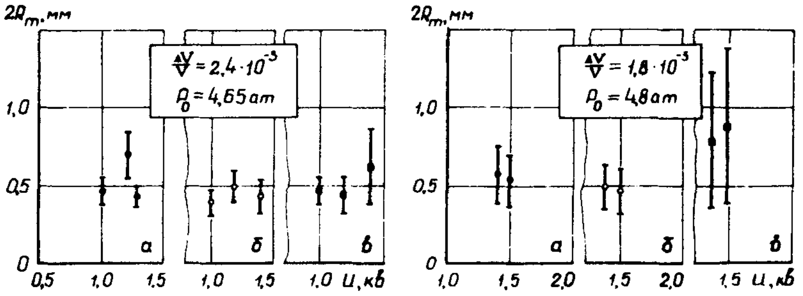


Fig. 9 Bubble size in liquid hydrogen at various emitter voltages a ': Dense tracks; δ - single track bubbles; б: single cavities of parasitic boiling (cavitation).

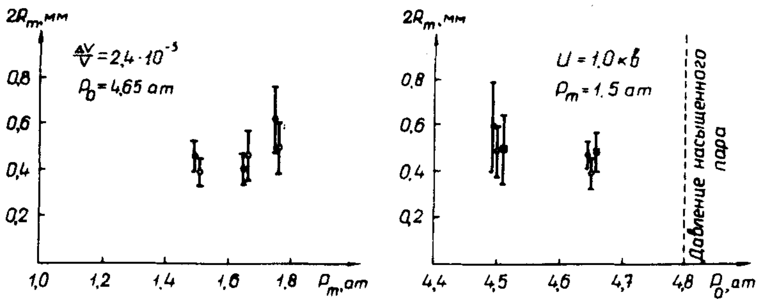


Fig.10 Bubble size in liquid hydrogen at various ultrasound pressure amplitudes P_m and at various pressure P_o in the chamber.
● dense tracks; o single track bubbles; ▮ single cavities of parasitic boiling (cavitation) on the emitter surface.