## NOTATION

g, free-fall acceleration; $\Delta P$, hydraulic resistance of the circulating heat-transfer agent in the AGHP along a closed circuit; $\rho$, density of the liquid heat-transfer agent; $\underline{a}$, acceleration; L, length of heat-transfer section of the AGHP; $\phi$, slope angle of the AGHP to the horizontal; $\sigma$, surface tension; $\Theta$, wetting angle; $\bar{d}$, mean diameter of the AGHP wick pores; $T_h$, $T_\ell$, temperature of the heater and condenser, respectively; $T_v$, $P_v$, temperature and pressure of the vapor in the heat supply zone; P, T, pressure and temperature of the saturated vapor of the heat-transfer agent at the phase boundary in the AGHP compensation cavity; $\Delta P_{\ell w}$, hydraulic resistance to the flow of liquid heat-transfer agent along the wick; $\Delta T_\sigma$, driving temperature difference; Bo, Bond number; $\Delta T$, $\Delta T_a$, temperature heads required to overcome the hydraulic and hydrostatic resistances, respectively; Q, heat flux transferred by the AGHP; $q_{surf}$, $q_{ax}$, heat flux densities in the heat supply zone and the transport zone (ratio of the heat flux transferred Q to the area of the heat supply zone and to the total area of the internal sections of the vapor channel and condenser channel, respectively); $\Delta P_{\sigma max}$, maximum capillary head.

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# VARIATION OF THE CONTACT ANGLE IN THE QUASISTATIC GROWTH OF A VAPOR BUBBLE ON A HORIZONTAL SURFACE IN A BOILING LIQUID

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UDC 532.64:536.423

The variation of the contact angle at the solid–liquid–vapor phase interface during the quasistatic growth of a bubble in the boiling of water is studied experimentally.

Scientists have been turning their attention in recent years to the variation of the contact angle at the phase interface in the process of growth of a vapor bubble. This interest is stimulated by the fact that the contact-angle dynamics determines to a large extent the stability of the vaporization centers as well as the bubble size and breakoff frequency [1-3]. In addition, the introduction of a bubble model with a "microlayer," i.e., a thin layer of liquid at its base, affords the most natural description of the dynamic angles during the motion of the bubble wall along the interface [3, 4]. The deviations of the contact angle from the equilibrium value are usually attributed to dynamic effects. The theory developed in [3] shows that the deviation of the contact angle is more pronounced, the higher the velocity of the bubble base. A comparison of the theoretical calculations with the experimental data [1, 2] shows that if only dynamic effects are considered, it is impossible to describe completely the behavior of the contact angle as the bubble grows. It is important in this connection to investigate experimentally the variation of the contact angle during the slow growth of a vapor bubble, when dynamic effects are negligible.

We have carried out a series of experiments, during which we determined the fundamental laws governing the variation of the base of a vapor bubble and the corresponding variations of the contact angle under various conditions of wetting of the heat-emitting surface by the boiling liquid. We investigated the boiling of distilled water on a horizontal surface. The heating surface was a nickel plate of length $5\cdot10^{-2}$ m, width $5\cdot10^{-3}$ m, and thickness

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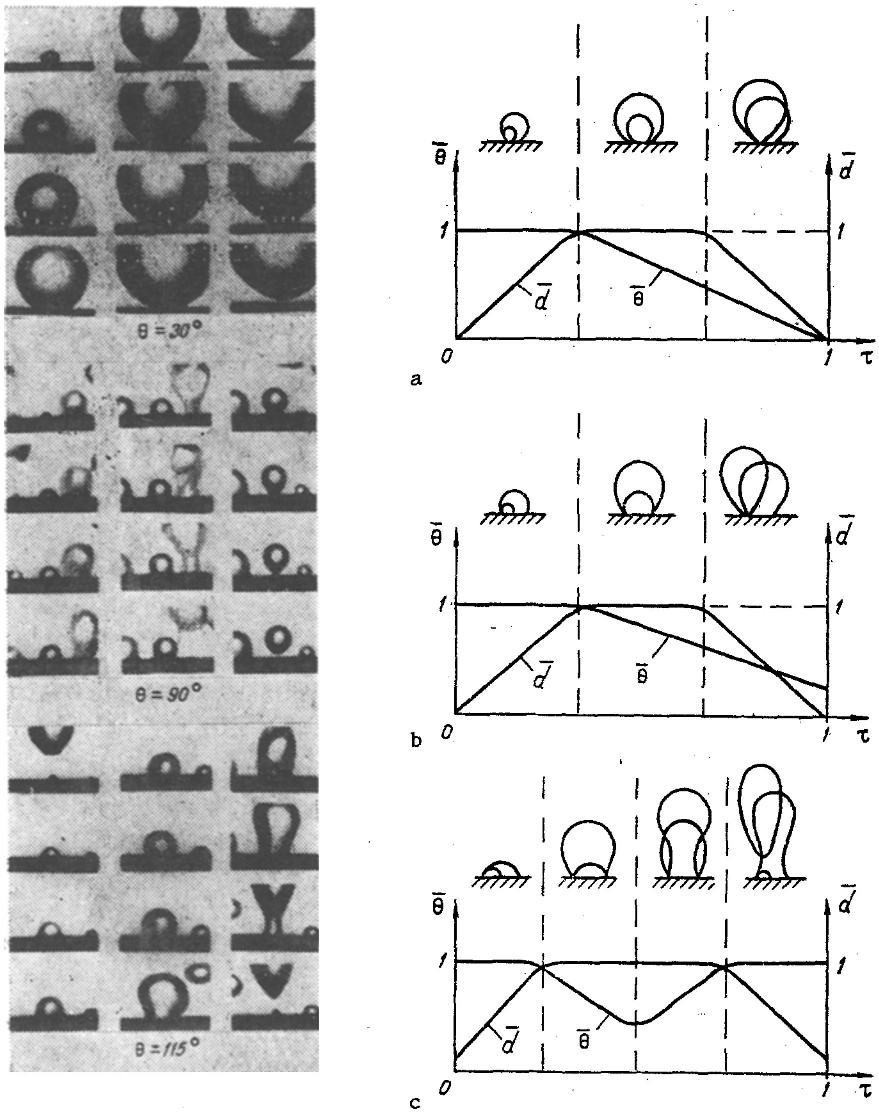


Fig. 1. Variation of the contact angle under various wetting conditions. a) Good wetting, $\Theta < 50°$; b) in the interval $50° < \Theta < 90°$; c) poor wetting, $\Theta > 90°$.

$1 \cdot 10^{-4}$ m, which was heated by a constant electric current. The physicochemical conditions at the phase interface were varied by treating the heating surface [5] in such a way as to produce equilibrium contact angles in the interval 30-110°. The bubble-growth processes were filmed with an SKS-1M high-speed motion-picture camera. The exposed and developed films were processed according to the procedure described in [1]. A series of frames with pictures of the bubble at various stages of its growth was selected. An image of the bubble was obtained on a Mikrofot apparatus, which was also used to enhance the bubble contour and the solid–liquid interface. The resulting contours were overlaid so that the solid–liquid interfaces and one of the contact points of the bubble wall with the solid surface coincided. This technique made it possible to discern qualitatively the relationship between the motion of the bubble wall over the heating surface and the variation of the contact angle. Motion-picture frames of the growth of the vapor bubbles and the results of processing of the film for various wetting conditions are shown in Fig. 1.

It is evident from the figure that the laws of variation of the bubble bases and the contact angle in the first stage of growth coincide qualitatively in the cases of good and poor wetting. The diameter of the bubble base increases at first with a constant contact angle, then the growth of the base ceases, and the contact angle decreases. At a definite value of the contact angle in the interval of equilibrium values $\Theta < 90°$ the base begins to shrink. The liquid flows under the bubble and separates it from the heat-emitting surface.

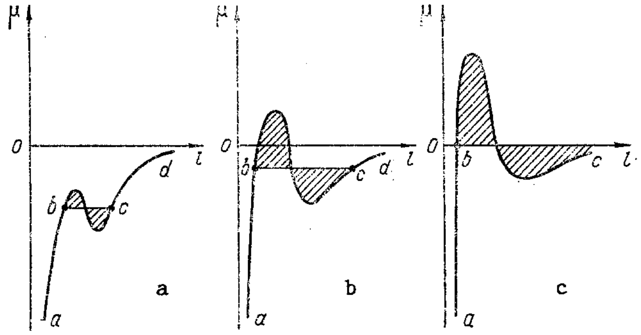


Fig. 2. Excess chemical potential vs thickness of the liquid film (isotherms). a) Good wetting; b) partial wetting; c) separation of partial wetting from complete nonwetting of the solid surface by the liquid.

In the case of poor wetting $\Theta > 90°$ the last stage differs qualitatively from the above-described situation. The contact angle decreases at first and then increases with a constant diameter of the wetting perimeter. The bubble elongates upward. The base begins to decrease after an equilibrium value of the contact angle is established.

The variation of the size of the bubble base and the contact angle is accompanied by effects that cannot, in principle, be explained entirely by dynamic effects. For example: 1) in the initial stage of the bubble base the contact angle is close to the equilibrium value, despite the fact that the rate of displacement of the wetting perimeter is a maximum at this instant; 2) an appreciable decrease of the contact angle is observed at a constant base diameter after the wetting perimeter attains its maximum value; 3) the process of contraction of the bubble base changes qualitatively in the case of poor wetting.

We consider the mechanism of the described effects from the point of view of the model of a bubble with a liquid microlayer at its base; the wedge effect (disjoining pressure) is inherent in this model. For an incompressible liquid under isothermal conditions the disjoining pressure is equal to minus the excess chemical potential of the layer per unit volume [4, 6]. Hypothetical relations for the excess chemical potential $\mu$ as a function of the layer thickness $\ell$ at $T$ = const are given in the general theory of van der Waals forces [6]. Some of them are shown in Fig. 2.

The microlayer under the vapor bubble is subjected to an excess pressure created by the curvature of the bubble surface. This pressure is equalized by the disjoining pressure of the microlayer. As the bubble increases in size, the Laplacian pressure diminishes, causing the equilibrium thickness of the layer to increase. This situation corresponds to displacement of the point characterizing the equilibrium of the layer upward along the isotherm from a to b. The variation of the contact angle is insignificant in this interval [7]. When the point b is reached, the layer enters the interval bc of metastable and completely unstable thicknesses, where the point c corresponds to a thick $\beta$-modification layer [4], which forms a zero contact angle with the bulk liquid [7]. In this stage of its growth the bubble loses its adherence to the solid surface, and the contact angle begins to decrease. We note that the abrupt increase in the thickness of the microlayer inhibits, on the one hand, the desorption process induced by the constant admission of heat to the surface and, on the other, the increase in the total energy as a result of the increased volume of the layer. When the contact angle decreases to a certain value, favorable conditions set in for an increase in the thickness of the microlayer as a result of the entry of liquid from the bulk phase, causing the base of the bubble to shrink and the bubble itself to break off from the surface.

Comparing the isotherms for good and poor wetting (Fig. 2), we note that as the wetting conditions deteriorate, first, the interval bc approaches the thickness axis and, second, the interval of unstable and metastable states of the layer increases. It follows from the first result that with deterioration of the wetting the situation is possible where the transition into the interval of unstable microlayer thicknesses corresponds to such a low pressure that the bubble breaks off much earlier as a result of the repulsive forces of the hydrostatic pressure. It follows from the second result, with allowance for the first, that in the case of sufficiently poor wetting an interval of equilibrium angles exists for which the microlayer enters the interval of unstable thicknesses during growth of the bubble and the contact angle begins to decrease. However, for large bubble diameters the hydrostatic repulsive forces play a definite role, elongating the bubble upward. The curvature of the bubble surface at its base increases, causing the pressure to increase and the microlayer to enter the interval ab of stable thicknesses for which an equilibrium contact angle is formed at the phase interface; this process appears to be confirmed by the high-speed motion pictures (see Fig. 1c).

The foregoing analysis has thus shown that the laws governing the variations of the size of the base and the contact angle in the quasistatic growth of vapor bubbles in a boiling liquid are qualitatively attributable to the specific properties of the liquid microlayer under the bubble.

## NOTATION

$\Theta$, contact angle (angle formed by the surface of the bulk liquid with the surface coated by a thin liquid layer); $\bar{\Theta}$, relative contact angle; d, diameter of bubble base; $\bar{d}$, relative diameter of bubble base; $\tau$, relative bubble growth time; $\mu$, excess chemical potential of microlayer per unit volume; $\ell$, thickness of liquid microlayer under vapor bubble.

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# HYDRODYNAMIC MECHANISM OF ABSORPTION-WAVE PROPAGATION IN A TRANSPARENT LIQUID UNDER THE ACTION OF A LASER PULSE


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The hydrodynamic approach is used to study the formation and movement of an absorption wave in water under the action of a pulse from a ruby laser.


The study of the effect of powerful laser radiation on a transparent liquid, begun in [1], is of considerable scientific and practical interest. Most recent studies of the absorption of radiation in transparent condensed dielectrics have been based on the notion

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