

Taking into account that $\tau = 2 \cdot 10^{-8}$ sec, we obtain the energy density required: $\sim 150 \text{ J/cm}^2$.

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ROLE OF BUBBLE BOILING IN THE INTERACTION OF INTENSE RADIATION WITH MATTER

A. V. Burmistrov

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The model of stable evaporation [1-4] is widely used to study the interaction of intense radiation with matter. In this model the radiation flux normally incident on a planar surface of the body is constant in magnitude, which also guarantees stationarity of parameter distributions in a coordinate system related to the surface. An assumption of the model is that evaporation occurs at the surface only. As noted in [1, 2], however, in establishing metal evaporation the surface is found to be in a liquid overheated state. Consequently, the evaporation mechanism can be complicated by bubble boiling. This process is usually neglected due to the fact that the surface tension coefficient of metals is large (if the temperature is not too close to the critical temperature), and, consequently, the probability of bubble formation is low [2]. Quantitative estimates are needed to justify this statement. Such estimates were carried out in [5, 6], where it has been shown that there exists a certain intensity flux q_* , above which surface evaporation is modified by bulk boiling. A number of inaccuracies, however, were admitted in [5, 6], which, as shown below, strongly distort the boundaries of the evaporation mechanisms in several cases. The purpose of the present study is to remove these inaccuracies and calculate the quantity q_* more correctly.

1. Vapor bubbles occur in a liquid either as a result of thermal fluctuations (fluctuating bubbles) or due to extraneous impurities (stationary bubbles) [6].

Only bubbles whose radius exceeds a critical r_* , determined from the equation [7]

$$p_0(T) \exp\left(-\frac{2v\sigma}{r_*kT}\right) = p + \frac{2\sigma}{r_*}, \quad (1.1)$$

participate in boiling. In this expression p_0 is the saturated vapor pressure over a planar surface; σ , surface tension coefficient; p , pressure in the liquid; and v , mean volume of the liquid (calculated per molecule).

At temperatures not too close to the critical temperature, where the liquid can be separated into gas-like phases, i.e., the vapor density is much lower than the liquid density ($\rho_{\text{vap}} \ll \rho_{\text{liq}}$), Eq. (1.1) has the approximate solution

$$r_* = \frac{2\sigma}{p_0(T) - p} = \frac{2\sigma}{\Delta p}. \quad (1.2)$$

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Equation (1.2) is inapplicable only in a small neighborhood of the critical temperature, where the inequality $\rho_{\text{vap}} \ll \rho_{\text{liq}}$ is violated, and which is of no interest to us, since due to the impossibility of separating the liquid and gas phases in this region it is meaningless to talk either about a surface of the liquid or about bubbles.

To estimate the effect of boiling on the evaporation process, it is necessary to consider the generation and growth of supercritical bubbles in a superheated layer.

2. We obtain the temperature distribution in an evaporating material.

Unlike [6], we solve the problem taking into account the energy cost in heating the vapor, melting, and the finite width of the melting layer. In the energy conservation equation

$$\rho u(h + u^2/2) + q = \text{const}$$

we substitute the following expressions for the enthalpy and energy flux:

$$\begin{aligned} h &= C_p T + h_0, \\ q &= q_r + q_T = q_r^0 (1 - R) e^{-\mu x} - K \frac{dT}{dx}, \end{aligned}$$

where ρ , u , h , and T are the density, velocity, enthalpy, and temperature; C_p , R , μ , and K , temperature, reflection coefficient, absorption, and thermal conductivity, assumed constant for simplicity; h_0 , a quantity taking into account melting enthalpy; and q_r^0 , q_r , and q_T , fluxes of incident radiation, radiation in the material, and thermal flux.

As a result we obtain the temperature equation

$$\rho u \left(C_p T + h_0 + \frac{u^2}{2} \right) + q_r^0 (1 - R) e^{-\mu x} - K \frac{dT}{dx} = \text{const}. \quad (2.1)$$

The density of the condensed material is assumed constant ($\rho = \rho_0 = \text{const}$); therefore the velocity is also constant: $u = u_0$.

The boundary conditions are

$$T|_{x=\infty} = 0, \quad \left. \frac{dT}{dx} \right|_{x=\infty} = 0 \quad (2.2)$$

and the conditions at the melting surface are

$$h_0(x_{\text{me}} - 0) - h_0(x_{\text{me}} + 0) = \lambda_{\text{me}}, \quad T(x_{\text{me}}) = T_{\text{me}}. \quad (2.3)$$

At $x > x_{\text{me}}$ we put $h_0 \equiv 0$. From the boundary conditions (2.2) the constant in the right-hand side of Eq. (2.1) is then determined: $\text{const} = \rho_0 u_0^3 / 2$. The equation acquires the form

$$\begin{aligned} \rho_0 u_0 (C_p T + h_0) + q_r^0 (1 - R) e^{-\mu x} - K \frac{dT}{dx} &= 0, \\ h_0 &= \begin{cases} 0, & x_{\text{me}} < x, \\ \lambda_{\text{me}}, & 0 < x < x_{\text{me}}, \end{cases} \end{aligned}$$

where λ_{me} is the specific melting heat.

Replacing for convenience u_0 by the effective evaporation heat

$$\lambda_{\text{eff}} = \frac{q_r^0 (1 - R)}{\rho_0 |u_0|} \quad (2.4)$$

and introducing the dimensionless quantities $T^* = T/T(0)$, $x^* = \mu x$, we obtain

$$-\beta \frac{dT^*}{dx^*} + e^{-x^*} = \alpha (T^* + h_0^*), \quad (2.5)$$

where $\beta = K\mu T(0)/q_r^0 (1 - R)$; $\alpha = C_p T(0)/\lambda_{\text{eff}} = 1/\lambda_{\text{eff}}^*$; $h_0^* = h_0/C_p T(0)$. The solution of Eq. (2.5) is

$$T^* = \frac{1}{\alpha - \beta} e^{-\frac{\alpha}{\beta} x^*} \left[e^{x^* (\frac{\alpha}{\beta} - 1)} - 1 + (\alpha - \beta) (1 + \lambda_{\text{me}}^*) \right] - \lambda_{\text{me}}^* \quad (2.6)$$

where $\lambda_{\text{me}}^* = \lambda_{\text{me}}/C_p T(0)$. From (2.3), (2.6) we have the coordinate of the melting front

$$\frac{\alpha}{e^{\beta} x_{me}^*} = \frac{(\beta - \alpha)(1 + \lambda_{me}^*) + 1}{(\beta - \alpha)(T_{me}^* + \lambda_{me}^*) e^{-x_{me}^*}} \quad (2.7)$$

Consider separately the cases $\beta \gg \alpha$ and $\beta \ll \alpha$. The first inequality occurs for not too high intensities. For example, for metals irradiated by visible and infrared radiation ($K \approx 1 \text{ W} \cdot \text{cm}^{-1} \cdot \text{deg}^{-1}$, $T(0) \approx 2 \cdot 10^3 \text{ K}$, $\mu \sim 10^5 \text{ cm}^{-1}$), it is satisfied for fluxes $q_r^0(1-R)\beta \ll 3 \cdot 10^9 \text{ W/cm}^2$. In the region of stable evaporation characteristic values are $\alpha \sim 10^{-1}$ and $(1-R) \approx 0.5$; therefore the inequality $\beta \gg \alpha$ is equivalent to $q_r^0 \ll 6 \cdot 10^9 \text{ W/cm}^2$. For $\beta \gg \alpha$ the inequality $e^{-x_{me}^*} \ll (\beta - \alpha)(T_{me}^* + \lambda_{me}^*)$ is valid; therefore we obtain from (2.7)

$$x_{me}^* \approx \frac{\beta}{\alpha} \ln \frac{(1 + \lambda_{me}^*) + 1}{(T_{me}^* + \lambda_{me}^*) \beta}, \quad x_{me}^* \approx \frac{K \lambda_{eff}}{q_r^0(1-R)C_p} \ln \frac{(1 + \lambda_{me}^*) \beta + 1}{(T_{me}^* + \lambda_{me}^*) \beta}$$

The opposite limiting case $\beta \ll \alpha$ corresponds to intensities $q_r^0 \gg 6 \cdot 10^9 \text{ W/cm}^2$, for which the above consideration of absorbing layer is not valid, since the disruption mechanism becomes hydrodynamic [4]. Nevertheless, the value of x_{me} , corresponding to the case $\beta \ll \alpha$, provides a qualitative concept on the behavior of the width of a melting layer at high intensities. Besides, for materials and radiations for which the absorption coefficient $\mu \ll 10^5 \text{ cm}^{-1}$, the inequality $\beta \ll \alpha$ can be achieved even at temperatures significantly lower than the critical. In this limiting case

$$x_{me}^* \approx \ln \frac{\lambda_{eff}}{\lambda_{me}^* + T_{me}^*}, \quad x_{me}^* \approx \mu^{-1} \ln \frac{\lambda_{eff}}{\lambda_{me}^* + T_{me}^*}$$

The ratio β/α has a simple physical meaning. It equals the ratio of characteristic thermal conductivity length $\delta_T = K/\rho_0 C_p |u_0|$ to the width of the absorption layer $\delta_q = \mu^{-1}$. For $\beta \gg \alpha$ the width of the superheated layer is determined by the thermal conductivity length, and in the opposite case by the absorption width.

It is necessary to point out that in real experimental conditions a transverse pressure gradient occurs due to the finite size of spots and liquid obstruction along the surface. As shown in [8], this effect significantly affects the width of the liquid layer at intensities $q < q_p$, where

$$q_p = \frac{\lambda \rho_0}{1-R} \left(\frac{a}{d} \right)^{2/3} (2\pi u_x)^{1/3}$$

(a is the thermal conductivity coefficient; d , spot size; and u_x , vapor velocity in a direction perpendicular to the surface of the metal). For a spot of size $d=1 \text{ cm}$ the intensity q_p is on the order of 10^6 W/cm^2 .

In the present study a drift of the liquid layer is not taken into account, which is justified for spots not too small.

In a melting layer we have a maximum temperature:

$$x_m^* = \frac{\beta}{\alpha - \beta} \ln \left\{ \frac{\alpha}{\beta} [(\beta - \alpha)(1 + \lambda_{me}^*) + 1] \right\},$$

$$T_m^* = \frac{1}{\alpha - \beta} \left\{ \frac{\alpha}{\beta} [(\beta - \alpha)(1 + \lambda_{me}^*) + 1] \right\}^{\frac{\alpha}{\beta - \alpha}} \left\{ \frac{\alpha}{\beta} [(\beta - \alpha)(1 + \lambda_{me}^*) + 1] - 1 + (\alpha - \beta)(1 + \lambda_{me}^*) \right\} - \lambda_{me}^*$$

To transform to the dimensional temperature it is necessary to know the surface temperature $T(0)$ and the quantity λ_{eff} appearing in the parameter α . To determine both these quantities it is necessary to consider vapor flow near the surface, since this flow carries part of the energy transported to the wall by radiation.

Assuming that the vapor is a monatomic ideal gas with constant heat capacity and the velocity at the Knudsen layer equals the sound velocity, which corresponds to evaporation in vacuum, the following relations were obtained in [1-4]:

$$q_r^0(1-R) = \rho_0 |u_0| \left[\lambda(T(0)) + \lambda_{me} + C_p(T(0) - T(\infty)) - 0.334 \frac{k}{M} T(0) \right]; \quad (2.8)$$

$$\rho_0 |u_0| = 0.82 p_0(T(0)) \sqrt{M/(2kT(0))}, \quad (2.9)$$

where k is the Boltzmann constant and M is the molecular mass.

The effective evaporation heat (see Eq. (2.4)) is also determined from Eqs. (2.8), (2.9):

$$\lambda_{eff} = \lambda(T(0)) + \lambda_{me} + C_p(T(0) - T(\infty)) - 0.334 \frac{k}{M} T(0). \quad (2.10)$$

The pressure $p_0(T)$ is determined by the phase equilibrium equation, which, according to [1], is

$$\lg p_0(T) = a - b/T. \quad (2.11)$$

Using values of temperature and pressure at the boiling point and at the critical point ($p_v = 1.01$ bar, $T_v = 2621^\circ\text{K}$, $p_* = 2.8 \cdot 10^4$ bar, $T_* = 14,200^\circ\text{K}$ [6]), we obtain the phase equilibrium equation of aluminum:

$$\lg p_0 = 5.45 - 14260/T.$$

The temperature dependence of the evaporation heat is approximated by the linear function

$$\lambda(T) = \lambda_0(T_* - T)/(T_* - T_v),$$

where λ_0 is the evaporation heat at the normal boiling temperature, equal to 10^4 J/deg for aluminum. The growth of supercritical bubbles and their critical radius are determined not only by temperature, but also by the pressure in the liquid, created in the given case by jet reaction. In vacuum evaporation the vapor pressure at the surface p differs by a constant from the equilibrium pressure p_0 , corresponding to the surface temperature [3, 4]

$$p = 0.53p_0. \quad (2.12)$$

In [6] the pressure p was calculated by the semiempirical equation

$$p = Cq_r^0 \quad (C_{Al} = 4 \text{ dyn} \cdot \text{sec}/l) \quad (2.13)$$

(the proportionality between pressure and the radiation flux follows also from Eqs. (2.8), (2.9), and (2.12), taking into account that according to (2.8), (2.9), and (2.11) the surface temperature depends on q_r^0 only logarithmically). Obviously, for materials for which the value of the constant C is experimentally determined, the pressure is best calculated by Eq. (2.13), without solving system (2.8), (2.9), (2.11), as was also done in [6]. The surface temperature, however, was calculated in [6] from the pressure directly from the phase equilibrium equation, which is erroneous. In reality the vapor and liquid equilibrium does not exist, and the surface is found in a strong superheated state (see Eq. (2.12)). Account of superheating can affect the boundary of evaporation mechanisms q_* , since the formation rate of bubbles depends exponentially on the amount of superheating (as noted in [6] a small enhancement in temperature leads to enhancement in the formation rate of bubbles by many orders of magnitude). In [5] the strong lowering of superheating (not more than 1°C) was also used. As a result the authors have reached a conclusion concerning the negligibly small role of fluctuating bubbles.

In the present paper the jet pressure p is calculated by Eq. (2.13), but the surface temperature is calculated from the phase equilibrium equation, taking into account the fact that the equilibrium pressure is related to the jet pressure by Eq. (2.12). Another inaccuracy was committed in [6] in calculating the quantity λ_{eff} appearing in the parameter α . It consists of the fact that the enthalpy and kinetic energy of the vapor (the last term in Eq. (2.10)) were not taken into account, although the expenditure at heating the metal is included. This is incorrect, since the term not included is of the same order as the cost of heating the metal, and at high temperatures provides an important contribution to λ_{eff} . Under these conditions account of vapor enthalpy can significantly affect the magnitude of superheating, and, consequently, strongly change the formation rate of bubbles.

3. The applicability region of the surface evaporation model must be determined from the condition of smallness of perturbation due to bubbles (e.g., the smallness of the ratio of bubble flux of the vapor to the total mass discharge). It is necessary to choose a certain value of the perturbation, above which the role of boiling is assumed important. Its specific choice, however, has little effect on the quantity q_* , since the number of bubbles and the physical quantities related to them depend strongly on the radiation intensity. For the same reasons an approximate estimate of the quantities related to boiling is sufficient.

A criterion of destruction of surface evaporation by bulk boiling was formulated [6] in the form of an equality of area of all supercritical bubbles with the area of liquid surface, and is of the form

$$K_0 = \pi \delta_{T,q} d_b^2 N_b = 1, \quad (3.1)$$

where $\delta_{T,q}$ is the width of the superheated layer, d_b is the mean diameter of supercritical bubbles, and N_b is their mean number per unit volume.

Consider the physical reasons of destruction of surface evaporation by bulk boiling in more detail. First, due to boiling, besides vapor flow directly at the surface there exists a flow due to ejected bubbles. The criterion of surface evaporation destruction by this bulk effect is

$$K_1 = \frac{\pi \rho_b}{6 \rho_0} d_b^3 N_b = 1.$$

Indeed, the "bubble" flow of the vapor with a single surface is estimated by the equation $(4/3)\pi(d_b/2)^3 \rho_b N_b |u_0|$, and the mass flow for surface evaporation is $\rho_0 |u_0|$ (ρ_b is the vapor density in the bubble).

Secondly, for bubble formation and growth energy expenditure is needed. The bubble formation energy consists of surface energy $4\pi(d_b/2)^2 \sigma$, evaporation energy $(4/3)\pi(d_b/2)^3 \rho_b \lambda$, and expansion work on the order of $(4/3)\pi(d_b/2)^3 \rho_b kT$. For precritical temperatures $kT < \lambda$, therefore, the expansion work does not exceed the evaporation energy and can be neglected in estimates. Consequently, the power expended for bubble formation is estimated by the expression

$$N_b |u_0| \left[4\pi \left(\frac{d_b}{2}\right)^2 \sigma + \frac{4}{3} \pi \left(\frac{d_b}{2}\right)^3 \rho_b \lambda \right] \simeq \frac{\pi}{6} d_b^3 \rho_b \lambda \left(1 + \frac{\rho_0 a_0}{\rho_b d_b} \right) N_b |u_0|,$$

where a_0 is of the order of the molecular size (the approximate relation $\sigma \simeq \lambda \rho_0 a_0 / 6$ was used).

Since the evaporation cost directly at the surface equals $\rho_0 |u_0| \lambda$, one can write down the following "energetics" criterion for surface evaporation by bulk boiling:

$$K_2 = \frac{\pi \rho_b}{6 \rho_0} \left(1 + \frac{a_0 \rho_0}{d_b \rho_b} \right) d_b^3 N_b = 1.$$

Thirdly, starting from the surface of the liquid, the bubbles "deteriorate" it, creating an unevenness of the order of its radius. It can be assumed that the surface is considerably damaged if the area of the bubbles intersecting the planar surface of the liquid $N_b \pi d_b^2 S$ equals the area of the surface itself S . Hence

$$K_3 = \pi d_b^2 N_b = 1. \quad (3.2)$$

Condition (3.2) implies that the irradiated area exceeds significantly the area of the planar surface, which may indicate power absorption. It also follows from (3.2) that the distance between neighboring bubbles is on the order of their diameter. Consequently, the structure of the absorbing layer differs strongly from the characteristic structure for surface evaporation. Besides, emerging from the surface, densely arranged bubbles can eject the liquid filling the portion between them in the form of particles of approximately the same radius as the bubbles. Such a "drop cover" was discussed, e.g., in [9]. It can be seen that when criterion (3.2) is satisfied the drop flux mass $\rho_0 |u_0| N_b d_b^3$ is on the order of the total flux $\rho_0 |u_0|$ (it is understood that a bursting bubble creates a droplet of the same size). Thus, the "drop cover" significantly affects the mass carried out. Besides, it can strongly enhance the screening of the surface from the radiation [4, 9].

The quantities K_1, K_2, K_3 increase with intensity q_T^0 . For some intensity q_* one of them becomes equal to unity, which also implies modification of surface evaporation by bulk boiling.

Since $K_1 < K_2 \ll K_3$ the modification of evaporation mechanisms is determined by the criterion K_3 , and effects related to K_1 and K_2 are of secondary value. Comparing K_3 with the criterion K_0 , used in [6], we have $K_0 = K_3 \delta_{T,q} / d_b > K_3$; consequently, the criterion K_0 must lead to lowering of the quantity q_* . As will be shown below, an error was committed in [6] in estimating the mean bubble diameter, as a result of which the criterion K_0 is still more enhanced (the enhancement reaches four orders of magnitude). This, in turn, led to a still larger lowering of q_* (in several cases more than two orders of magnitude). The bubble diameter at the moment of contact with the surface equals

$$d_b = \int_0^{t_l} v(t) dt = \int_0^{t_l} \sqrt{(2/3) \Delta p(t) / \rho_0} dt.$$

where t_l is the lifetime of the bubble up to contact with the surface and v is the growth rate of the bubble (as in [6], it is taken equal to the Rayleigh velocity $v = \sqrt{(2/3) \Delta p / \rho_0}$). The following approximate estimate is sufficient:

$$d_b \simeq v_m t_l = \sqrt{(2/3) \Delta p_m / \rho_0} t_l,$$

where $v_m = \sqrt{(2/3) \Delta p_m / \rho_0}$ is a characteristic growth rate of bubbles and $\Delta p_m = p_0(T_m) - p$.

Bubble growth occurs in a layer with a temperature gradient. Nonuniformity of the temperature field leads to a nonsymmetric mass flow through the surface of the bubble and to generation of a resulting evaporation force at the bubble [10]. Estimates based on the results of [10] show that for bubbles of size less than 10^{-2} cm the directed velocity acquired under the action of the evaporation force is small in comparison

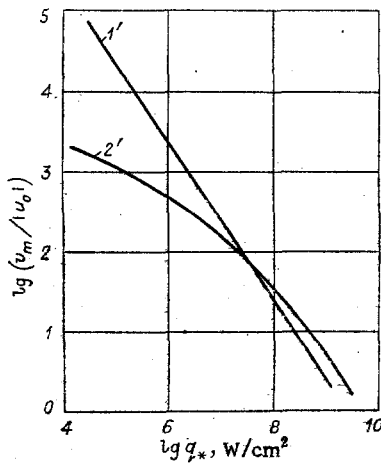


Fig. 1

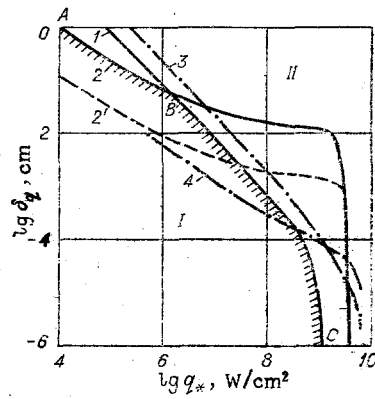


Fig. 2

with the velocity of radial expansion of the bubble. In most characteristic cases bulk boiling develops at high intensities, when the width of the liquid layer does not exceed 10^{-2} cm. Therefore, effects related to evaporation forces are neglected in the present paper. The bubble lifetime is determined by the time up to contact with the surface of the liquid. The following estimates are used in [6]:

$$t_l = \delta_{T,q}/|u_0|, \quad d_b = \delta_{T,q}v_m/|u_0|. \quad (3.3)$$

They are valid, however, only when the bubble approaches the surface with a velocity $|u_0|$. In real situations the velocity of the bubble boundary relative to the surface equals $|u_0| + v$; therefore in the general case the correct estimates are

$$t_l = \delta_{T,q}/(|u_0| + v_m), \quad d_b = \delta_{T,q}v_m/(|u_0| + v_m). \quad (3.4)$$

Expressions (3.3) and (3.4) are equivalent only when $v_m \ll |u_0|$, but calculations show that for intensities near q_* the opposite inequality really occurs (the q_* dependence of $v_m/|u_0|$ is represented in Fig. 1). Therefore, the estimates (3.3) lead to strong enhancement of d_b and of the criterion K_0 .

Substituting (3.3) into (3.1), we find

$$K_0 = \pi \delta_{T,q} N_b (v_m/|u_0|)^2.$$

The criterion K_3 , calculated by Eq. (3.4), equals

$$K_3 = \pi \delta_{T,q} N_b v_m^3 / (|u_0| + v_m)^3.$$

Below we calculate q_* by means of criterion K_3 , and compare it with q_* value calculated from K_0 .

As shown above, the width of the superheated layer $\delta_{T,q}$ is determined by the thermal conductivity length δ_T at low intensities, while at high intensities it is determined by the absorption length δ_q . Therefore, in the general case we use the estimate

$$\delta_{T,q} = \delta_T + \delta_q = \delta_q(1 + \beta/\alpha).$$

Following that K_3 is transformed to the form

$$K_3 = \pi \delta_q^3 (1 + \beta/\alpha) N_b \frac{\sqrt{\frac{2}{3\rho_0} \frac{\beta}{\alpha} \Delta p_m^{1/2}}}{1 + \sqrt{\frac{2}{3\rho_0} \frac{\beta}{\alpha} \Delta p_m^{1/2}}}.$$

The quantity N_b is the number of supercritical bubbles per unit volume, being [6]

$$N_b \approx 10^{-10} / (2r_{*m}^2),$$

where $r_{*m} = 2\sigma_m/\Delta p_m$ is a characteristic critical radius and $\sigma_m = \sigma(T_m)$. The temperature dependence of $\sigma(T)$ (as well as $\lambda(T)$) is very well approximated by the linear function

$$\sigma(T) = \sigma_0(T_* - T)/(T_* - T_v).$$

For aluminum $\sigma_0 = 737$ dyn/cm [11].

The formation rate of fluctuating supercritical bubbles equals, according to Frenkel's theory [12],

$$I_f = n_i \sqrt{\frac{2\sigma}{\pi M}} \exp\left(-\frac{\lambda M}{kT}\right) \exp\left(-\frac{4\pi r_*^2 \sigma}{3kT}\right).$$

The number of these bubbles formed per unit volume during the lifetime of the bubble is

$$N_{bj} \simeq I_f(T_m) \tau = I_f(T_m) \frac{\delta_{T,q}}{|u_0| + v_m},$$

where $|u_0|$ can be calculated by the equation $|u_0| = a/\delta_T = (a\alpha)/(\delta_Q\beta)$ (a is the temperature conductivity coefficient).

4. Figures 1 and 2 present results of calculating critical intensities by the K_3 criterion for fluctuating and stationary bubbles, respectively. The curve 2' corresponds to stationary bubbles and was calculated by the K_0 criterion, without taking into account the intrinsic growth rate of the bubble. For large absorption widths δ_Q the K_0 criterion leads to a significant error in q_* . For $\delta_Q = 10^{-2}$ cm, e.g., the error exceeds three orders of magnitude. This is a consequence of the fact that in boiling the bubble growth rate v_m significantly exceeds the velocity of front evaporation $|u_0|$. Curve 2' in Fig. 1 corresponds to stationary bubbles; i.e., it describes the change in the quantity $v_m/|u_0|$ along curve 2' in Fig. 2. Curve 1' corresponds to fluctuating bubbles.

Curve 1' of Fig. 2, corresponding to fluctuating bubbles and criterion K_0 , is not given, since it differs little from curve 1 (the intensities q_* calculated by K_3 and K_0 differ by no more than several percent).

The results of the calculations differ substantially from the results of [6], represented by curves 3 and 4. In the region of variation of δ_Q the stationary dependence 4 is below the fluctuating 3. Thus, according to [6] fluctuating boiling plays an important role only for $\delta_Q < 6.0 \cdot 10^{-5}$ cm. The location of curves 1, 2, found in the present work, is different: The largest part of the fluctuating curve 1 is below 2. As a result fluctuating boiling is the main mechanism of vapor formation in a significantly wider region of values of δ_Q ($\delta_Q < 5.6 \cdot 10^{-2}$ cm). The curve ABC is the boundary of region I, in which bulk boiling plays no role.

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