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On the Mechanism of Initiation of Boiling of Liquid Metastable Systems by Ionizing Radiation

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A CERTAIN concentration of like-charged ions undoubtedly gives rise to an embryonic micro-burst of a liquid in which an essential role of the electropoles of the ions appears not only in the repulsion of the ions but also in the realization of binding of ions to molecules. In the calcuation of the number of bubbles which are formed as a result of the aggregation of ions in a liquid supersaturated with vapor[1] or gas[2,3], we shall assume as sufficient for the induced creation of a bubble that there originate in a region whose dimensions do not exceed the "interval of localizations" $\lambda(\xi)$ (ξ are parameters which characterize the degree of supersaturation) $\nu(\xi)$ positively charged ions, the electrons of which acquired an energy $\epsilon > \epsilon'_{imp}(\xi)$ upon ionization. (We shall call such ions noncompensated). The parameter ϵ'_{imp} characterizes the conditions of separation (averaged over all possible configurational dispositions of ν ions) for which the effect of oppositely charged centers becomes unimportant, at least in the time of formation of the embryonic cavity.

The probability $w(\epsilon_0)$ of creation of conditions adequate for the formation of an embryonic cavity somewhere along the track of a δ-electron, which has an initial energy ϵ_0, depends on the complex spatial distribution on noncompensated ions. We can, however, with sufficient confidence, assume that the most numerous δ-electrons with low energies give the chief contribution to the creation of the fluctuations which interest us. This circumstance facilitates the modeling of a distribution of noncompensated ions. Thus, for example, we can hypothesize that a large part of the noncompensated ions is formed near the tracks of low energy δ-electrons and the distributions of such ions is approximated closely by a Poisson distribution, in which the mean specific number of these noncompensated ions is related to the specific energy loss of an electron $\eta \approx (1/\epsilon_{imp})(d\epsilon/dx) \approx a/\epsilon_{imp}\epsilon$, where by ϵ_{imp} should be understood the energy loss which occurs (on the average) per noncompensated ion formed near the track ($\epsilon_{imp} \gtrsim \epsilon'_{imp}$). Then the probability of creation of the required groups per element of length dx averaged over the track of a δ-electron is

$$dw \approx \eta \frac{(\lambda\eta)^{\nu-1}}{(\nu-1)!} dx \quad \text{for} \quad \lambda\eta \ll 1;$$

$$\text{and } w(\varepsilon_0) \approx \int_{\nu\varepsilon_{imp}}^{\varepsilon_0} dw(\varepsilon) + w_1(\varepsilon_0);$$

where $w_1(\epsilon_0)$ is the additional probability of a sought fluctuation at the origin of the track of a δ-electron. Integrating over the spectrum of the δ-electrons, we obtain the specific number of bubbles:

$$n_{elect} \approx \int_{\nu\varepsilon_{imp}}^{\varepsilon_{max}} w(\varepsilon_0) \frac{KZ^2}{\beta^2}\frac{d\varepsilon_0}{\varepsilon_0^2}$$

$$\approx \frac{KZ^2}{\beta^2} \frac{(a\lambda)^{\nu-1}}{(\nu-1)!\,(\nu\varepsilon_{imp})^{\nu-1}\varepsilon_{imp}^{\nu}} \left(\frac{1}{\nu-1} + \frac{1}{\nu^2}\right) \approx \frac{Z^2}{\beta^2}\psi_\nu(\xi),$$

on disregarding the relativistic corrections and the weak dependence on the upper limit (Z and β are the charge and speed of an ionizing particle).

A characteristic of the process of ionic initiation in certain liquids should be noted. Thus, for example, in pure liquids of inert elements in which formation of negative molecular ions does not occur, the energy necessary for sufficient removal of electrons from ionized molecules, which take part in the formation of cavities, must be anomalously large to avoid recombination of ions with high mobility electrons before completion of formation of a cavity. Therefore, the intensity of a track in bubble chambers with inert liquids must increase with addition of certain substances which form negative ions.

In a series of events, a certain apparently relatively small number of bubbles can be formed as a result of thermal spikes generated by nuclear collisions. In calculation of the number of such bubbles we must have in mind that under the moderate supersaturation conditions prevailing, single stage nuclear collisions of ionizing particles with nuclei of atoms of the molecules of the liquid play the chief role in the creation of the necessary localization of kinetic energies of molecules. The mean energy of initiation, apparently, will not depend noticeably on the type of nucleus which has received the impulse in the collision, since this energy is further distributed among the neighboring molecules. A correct theoretical estimate of the energy necessary for "microburst" creation of embryonic voids does not appear possible, although there is some basis for thinking that it is rather large at moderate operating supersaturations in view of the dynamic resistances which arise. Assuming that the energy of initiation $\epsilon_{\text{init}}(\xi)$ exceeds the binding energy of atoms in the molecule, we obtain for the number of acts of transfer to nuclei of energy which exceeds ϵ_{init}

$$n_{\text{therm}} \approx \frac{\pi N_e}{\varepsilon_{\text{init}} M_p c^2}\left(\frac{Ze^2}{\beta}\right)^2 \approx \frac{Z^2}{\beta^2}\psi(\xi),$$

where N_e is the number of electrons per cubic centimeter of liquid and M_p is the mass of the proton. An estimate of the threshold energy for thermal initiation of boiling of some liquids for various supersaturations could be obtained by studying boiling of these liquids under the action of monochromatic neutrons, the energy of which can be varied over the range ~ 1-100 ev.

On increasing the degree of instability of the state, the initiation energy decreases and various microprocesses gradually come into effect, which guarantee a localization of thermal energy: multiple collisions, transformation of energy of excited molecules into kinetic energy of surrounding molecules, etc. The high transfer efficiency of electronic excitation energy to energy of motion of the nuclei of polyatomic molecules which is distributed in collisions with neighboring molecules can make the indicated process important in a series of concrete cases of formation of thermal spikes.

It would be natural to try to use the energy retained in the created ions for the purpose of developing a track after the passage of a particle, through some interval of time (~ 1 millisecond) sufficient for a pressure burst, i.e., for the creation of an automatically operating bubble chamber. The supersaturation necessary for retarded development of tracks must be such that the kinetic energy given off on neutralization of ionized polyatomic molecules exceeds the energy for initiation of boiling. (Various mechanisms of transformation of the energy liberated during neutralization into kinetic energy of molecules--the scattering of molecules which have been mutually neutralized, dissociation of a molecule excited during neutralization, collisions of the second kind, of surrounding molecules with a molecule excited on neutralization, etc.--give a kinetic energy which does not exceed a few electron volts.) For clear development of a track, it is necessary that a sufficient number of the ions which have remained recombine in the course of a short time interval. High specific ionization produced by the charged particles in the liquid, low coefficients of diffusion and of mobility of the ions, and the possibility of utilization of electropoles for variation of the dynamics of the recombination process of ions all create favorable conditions and allow confidence in the expediencey of attempts to set up automatic recording by going over to very high momentum-initiated superheats or supersaturations of operating liquids which contain polyatomic molecules.

According to the thermal model of electric breakdown of liquids proposed by Guntherschultz (see, for example, Ref. 4), one should also expect a manifestation of thermal spikes and vapor-gas nuclei upon "punctuated" energy loss by ions drifting in the electric field, even at pre-breakdown voltages. Therefore, use of a sufficiently strong electric field ("waiting" or switched on immediately after passage of a particle) can apparently either develop the track upon a "waiting" small superheat, or conserve the centers of development of the track until the creation of adequate supersaturation.

As another example of possible broadening of the range of varities of bubble chambers, one can cite the possibility of using the slow growth of bubbles and small background in a gas bubble chamber to demonstrate the recording of tracks of long range particles in opaque, physically-interesting, gassed liquids through bubbles which emerge on the free surface of the liquid (along the "torpedo-like" trail of the particle). In this case, some information on the spatial arrangement of a track can be estimated from the relative sizes of the bubbles along the track, as the size depends on the time needed to reach the surface.

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Consequences of Renormalizability of Pseudoscalar Meson Theory with Two Interaction Constants

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THE consequences of renormalizability of the pseudoscalar meson theory with two interaction constants obtained by Shirkov[1] are conveniently formulated as in Ref. 2.

The starting equations are again

$$\alpha(g_0^2, \lambda_0, \xi - L) = \alpha_c(g_c^2, \lambda_c, \xi) / \alpha_c(g_c^2, \lambda_c, L), \quad (1)$$
$$\beta(g_0^2, \lambda_0, \xi - L) = \beta_c(g_c^2, \lambda_c, \xi) / \beta_c(g_c^2, \lambda_c, L),$$
$$d(g_0^2, \lambda_0, \xi - L) = d_c(g_c^2, \lambda_c, \xi) / d_c(g_c^2, \lambda_c, L),$$
$$\mathscr{P}(g_0^2, \lambda_0, \xi - L) = \mathscr{P}_c(g_c^2, \lambda_c, \xi) / \mathscr{P}_c(g_c^2, \lambda_c, L).$$

One then introduces two effective charges $g(\xi)$ and $\lambda(\xi)$:

$$g^2(\xi) = g_0^2\alpha^2(g_0^2, \lambda_0, \xi - L) \quad (2)$$
$$\times \beta^2(g_0^2, \lambda_0, \xi - L)\, d(g_0^2, \lambda_0, \xi - L)$$
$$= g_c^2\alpha_c^2(g_c^2, \lambda_c, \xi)\, \beta_c^2(g_c^2, \lambda_c, \xi)\, d_c(g_c^2, \lambda_c, \xi),$$
$$\lambda(\xi) = \lambda_0 d^2(g_0^2, \lambda_0, \xi - L)\, \mathscr{P}(g_0^2, \lambda_0, \xi - L)$$
$$= \lambda_c d_c^2(g_c^2, \lambda_c, \xi)\, \mathscr{P}_c(g_c^2, \lambda_c, \xi).$$

The notation is the same as in Ref. 2. $\mathscr{P}$ is a quantity whose dependence on the meson-meson scattering amplitude P is given by[3]:

$$\mathscr{P} = (g_0^2 / 4\pi\lambda_0)\, P, \qquad \mathscr{P}_c = (g_c^2 / 4\pi\lambda_c)\, P_c,$$

λ_0 is a constant which appears in front of the Hamiltonian interaction terms*

$$(\lambda_0/4!)\,(\delta_{\tau_1\tau_2}\delta_{\tau_3\tau_4} + \delta_{\tau_1\tau_3}\delta_{\tau_2\tau_4} + \delta_{\tau_1\tau_4}\delta_{\tau_2\tau_3})\, \varphi_{\tau_1}\varphi_{\tau_2}\varphi_{\tau_3}\varphi_{\tau_4}.$$

The equivalence of the determination of the effective charges from either nonrenormalized or renormalized quantities follows from Eq. (1) and from the relations which exist between renormalized and nonrenormalized constants

$$g_0^2 = g_c^2\alpha_c^2(g_c^2, \lambda_c, L)\, \beta_c^2(g_c^2, \lambda_c, L)\, d_c(g_c^2, \lambda_c, L), \quad (3)$$
$$\lambda_0 = \lambda_c d_c^2(g_c^2, \lambda_c, L)\, \mathscr{P}_c(g_c^2, \lambda_c, L).$$

This is fundamentally confirmed by the fact that the logarithmic derivatives of α, β, d and $\mathscr{P}$ with respect to ξ are found to be solely dependent on the effective charges** g^2 and λ

$$\alpha'/\alpha = \alpha_c'/\alpha_c = F_1(g^2, \lambda), \quad \beta'/\beta = \beta_c'/\beta_c = F_2(g^2, \lambda), \quad (4)$$
$$d'/d = d_c'/d_c = F_3(g^2, \lambda), \quad \mathscr{P}'/\mathscr{P} = \mathscr{P}_c'/\mathscr{P}_c = F_4(g^2, \lambda).$$

Let us derive, for example, the last of Eqs. (4). The quantities g_c^2 and λ_c which appear in $\mathscr{P}_c'$ and $\mathscr{P}_c$ can be expressed in terms of g^2, λ and ξ by means of Eq. (2). Carrying this out, one obtains

$$\mathscr{P}'(g_0^2, \lambda_0, \xi - L) / \mathscr{P}(g_0^2, \lambda_0, \xi - L)$$
$$= F_4[g^2(g_0^2, \lambda_0, \xi - L), \lambda(g_0^2, \lambda_0, \xi - L), \xi].$$

This equation can only be satisfied if F_4 is not an explicit function of ξ; otherwise, if g_0^2 and λ_0 were kept constant, and ξ and L were varied, keeping their difference fixed, then ξ would be the sole variable appearing explicitly in F_4 only.

According to Eqs. (2) and (4), the logarithmic derivatives of the effective charges become

$$(g^2)'/g^2 = 2F_1(g^2, \lambda) + 2F_2(g^2, \lambda) \quad (5)$$
$$+ F_3(g^2, \lambda), \qquad \lambda'/\lambda = F_4(g^2, \lambda) + 2F_3(g^2, \lambda).$$

If the functions F are known, then Eqs. (5) define a system of differential equations which, together with the boundary conditions $g^2(L) = g_0^2$, $\lambda(L) = \lambda_0$, fully determine the effective charges $g^2(\xi)$ and $\lambda(\xi)$.

The functions F may be obtained from perturbation theory which applies if g_0^2, $\lambda_0 \ll 1$ and ξ is close to L, so that $g_0^2(L - \xi)$ and $\lambda_0(L - \xi)$ are small with respect to unity. We shall consider the