We study the process of boiling up (cavitation) in an asymmetric nuclear matter. The necessary condition for boiling is the equilibrium between the liquid and the saturated vapor phases. However, the boiling as a process means also the generation and the growth of the vapor phase (vapor bubbles) inside the liquid phase as a result of the heterophase fluctuations. In fact, the boiling can start in a metastable phase (overheated or extended liquid) only. If the pressure $P_0$ and the temperature $T_0$ provide a saturation of the vapor phase in the case of plane liquid-vapor boundary surface, the generation of the critical vapor bubbles of radius $R_{\text{crit}}$, which are in a thermodynamical equilibrium with the liquid, starts at higher temperature $T = T_0 + \Delta T$. The corresponding equilibrium condition for the chemical potentials in an asymmetric nuclear matter reads

$$
\mu_{\text{liq}}^q (P_0 - p, T_0, +)T, X_{\text{liq}}) = \mu_{\text{vap}}^q (P_0, T_0 + )T, X_{\text{vap}}),
$$

where $\mu_q$ is the chemical potential of the nucleon ($q=n$ for neutron and $q=p$ for proton), $X$ is the asymmetry parameter defined as

$$
X = (\rho_n - \rho_p)/(\rho_n + \rho_p),
$$

$\rho_n$ and $\rho_p$ are the neutron and proton densities, respectively. The indices “liq” and “vap” in Eq. (1) denote the liquid and vapor phases, respectively, and $\Delta p = 2\sigma / R$ is the capillary pressure due to the vapor bubble of radius $R$ where $\sigma$ is the surface tension coefficient. A solution to Eq. (1) allows us to obtain the critical radius $R_{\text{crit}}$ of the vapor bubble as a function of the overheating temperature $\Delta T$ for fixed values of $P_0$ and $X_{\text{liq}}$.

Using the temperature dependent Thomas-Fermi approximation [1] and a Skyrme-type force as the effective nucleon-nucleon interaction, we have solved the equilibrium equations (1) numerically. The dependence of the critical radius $R_{\text{crit}}$ on the overheating temperature $\Delta T$ for pressure $P_0 = 0.01$ MeV/fm$^3$ and asymmetry parameters $X_{\text{liq}} = 0$, $X_{\text{liq}} = 0.1$ and $X_{\text{liq}} = 0.2$ is presented in Fig. 1 (we have used here and below $\sigma = 0.9$ MeV/fm$^2$). We point out the increase of the critical radius $R_{\text{crit}}$ with the asymmetry parameters $X_{\text{liq}}$.

This is mainly due to the increase of the boiling temperature $T_0$ with the decrease of asymmetry parameter (see Ref. [1]).

Figure 1: Temperature dependence of the critical radius $R_{\text{crit}}$ for three cases of the asymmetry parameter $X=0$, $X=0.1$, and $X=0.2$. 

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The generation of the vapor bubble of arbitrary radius \( R \) is subsidized by a variation of the free energy \( \Delta F(R) \) which is given by

\[
\Delta F(R) = 4\pi\sigma(R^2 - \frac{2R^3}{3R_{\text{crit}}^3}). \tag{2}
\]

Figure 2 shows the dependence of the free energy \( \Delta F(R) \) on the vapor bubble radius \( R \) for certain values of parameters \( T_0=5.8 \) MeV, \( T = 1.2 \) MeV, and \( X_{\text{liquid}} = 0.2 \). The maximum of \( \Delta F(R) \) is located at \( R = R_{\text{crit}} \) and its position is shifted to smaller values of \( R_{\text{crit}} \) with an increase of the overheating temperature \( T \). The bubble radius \( R_{\text{crit}} \) is the critical point for the metastable phase in the following sense: to start the boiling up, i.e., to start the infinite growth of size of the bubbles, the system must pass through the barrier of \( \Delta F(R) \) to reach the region of \( R > R_{\text{crit}} \).

To evaluate the time evolution of the bubble radius \( R \) beyond the barrier at \( R > R_{\text{crit}} \), one needs to know the equation of motion for the collective variable \( R(t) \). We have studied this problem using the kinetic approach to the nuclear Fermi liquid [2]. Starting from the collisional kinetic equation, we have derived the following non-Markovian equation of motion for \( R(t) \) without restrictions on the amplitude of

\[
\Delta R = R(t) - R_{\text{crit}}:
\]

\[
B\ddot{R} + \frac{\partial B}{\partial R} \dot{R}^2 + \int_0^t \dot{R}(t') \exp\left(\frac{t'-t}{\tau}\right)\kappa(t,t') = -\frac{\partial \Delta F}{\partial R}, \tag{3}
\]

where \( B \equiv B(R) \) is the mass coefficient, \( \Theta \) is the relaxation time and \( \kappa(t,t') \) is the memory kernel. We have evaluated both transport coefficients \( B(R) \) and \( \kappa(t,t') \) assuming an irrotational motion of the Fermi liquid and taking into account the Fermi-surface distortion effects. Near the top of the barrier \( \Delta F \), the solution to Eq. (3) takes the following general form

\[
\Delta R = C_\zeta e^{\zeta t} + A_\zeta e^{-\Gamma t/2\hbar} \sin(Et/\hbar) + B_\zeta e^{-\Gamma t/2\hbar} \cos(Et/\hbar), \tag{4}
\]

The form of \( \Delta R \) given by Eq. (4) means that the growth of bubble size is accompanied by the characteristic oscillations of radius \( R \). These oscillations are due to the memory integral in Eq. (3). The characteristic energy, \( E \), the damping parameter, \( \Gamma \), and the instability growth rate parameter, \( \zeta \), depend on the relaxation time \( \Theta \) and the critical radius \( R_{\text{crit}} \). In Fig. 3 we show the dependence of the instability...
growth rate parameter $\zeta$, the energy of eigenvibrations, $E$, and the damping parameter, $\vartheta$, on the relaxation time $\tau$. The critical radius $R_{\text{crit}} = 4\text{fm}$ was taken the same as in Fig. 2. As seen from Fig. 3, the characteristic oscillations disappear in the short collision regime $\tau \to 0$, where the collective motion becomes Markovian. We point out that both the eigenenergy $E$ and the damping parameter $\vartheta$ depend on the temperature $T_0$. This fact can be used for an independent detection of the first order phase transition temperature $T_0$ in hot nuclei.

References