Equilibrium Surfaces of Hot Asymmetric Nuclear Matter

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We study the structure of the 3-dimension surface of equilibrium of asymmetric nuclear matter in variables P,T and X, where P is the pressure, T the temperature and $X = (N - Z)/(N + Z)$ is the asymmetry parameter. If the heated two-component liquid is surrounded by saturated vapor, the equilibrium condition requires that the pressure, $P_l(\rho_l, T, X_l)$, and the chemical potential, $\mu_{q,l}(\rho_l, T, X_l)$, of the liquid phase are equal to the corresponding ones, $P_v(\rho_v, T, X_v)$ and $\mu_{q,v}(\rho_v, T, X_v)$, for the saturated vapor, i.e.,

$$P_l(\rho_l, T, X_l) = P_v(\rho_v, T, X_v) \ ,$$

$$\mu_{q,l}(\rho_l, T, X_l) = \mu_{q,v}(\rho_v, T, X_v) \ . \qquad (1)$$

Here q denotes the isospin index of the nucleon. The existence of the stable state of the liquid phase under conditions (1) is only possible up to the critical temperature, T_{crit}. The two-component liquid and its saturated vapor co-exist with different asymmetry parameter, $X_l \neq X_v$, because of the ρ-dependence of the symmetry energy. That means that the vapor- and the liquid-branches are located on different van-der-Waals isotherms. The equilibrium state of two phases of a two-component system is described by the 3-dimension surface of equilibrium in variables P,T and X.

We have studied the thermal properties of asymmetric nuclear matter and the consequences of the equilibrium conditions of Eq. (1) within the framework of the Thomas-Fermi theory using an effective SkM [1] and Tondeur [2] interaction. In Fig. 1 we show the surface of equilibrium derived from Eq. (1) in the case of the SkM interaction. We point out that there are two sheets of the surface of equilibrium. The upper sheet is the surface of boiling and the under one is the surface of condensation. The interior space between both sheets represents the phase separation space. The crossing points of both sheets with a straight line $P = const, T = const$ give the equilibrium asymmetry parameters X_l and X_v for liquid and vapor phases, respectively. The intermediate points on the straight line between X_l and X_v represent the non-equilibrium state of the nuclear matter.

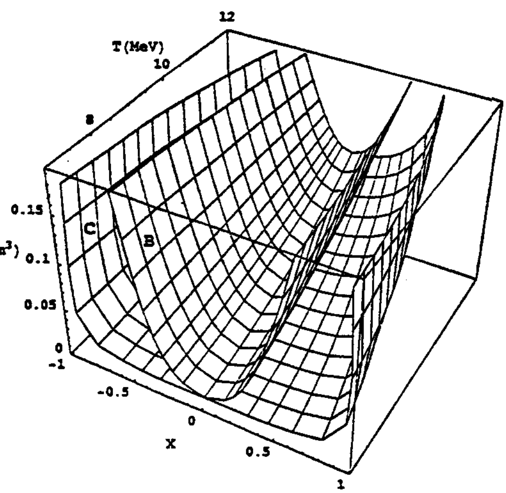

Figure 1. Fragment of the 3-dimension surface of equilibrium in P, T, X-space. Two sheets correspond to the surface of boiling (B) and the surface of condensation (C).

In general, asymmetry parameters X_l and X_v are different. The vapor asymmetry X_v exceeds the corresponding liquid one X_l (at $X_l > 0$). This is a feature of nuclear matter. The density dependence of the isospin symmetry energy provides the condition $|\mu_n| < |\mu_p|$ at $X_l > 0$ and the preferable emission of neutrons. In Fig. 2 we have plotted the temperature dependence of parameter X_v for certain values of the liquid asymmetry X_l.

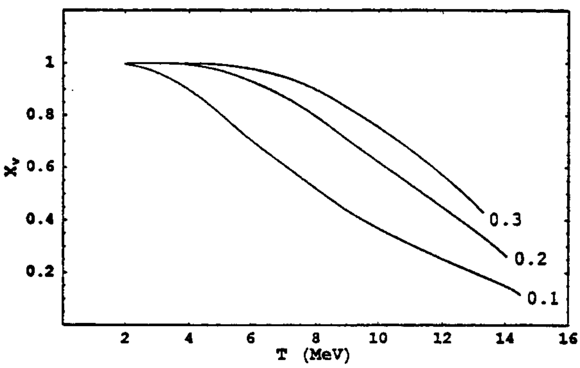

Figure 2. Vapor asymmetry parameter X_v taken on surfaces of equilibrium as functions of the temperature at fixed liquid asymmetry parameter X_l. Values of X_l are indicated by numbers near the curves.

The above mentioned sheets of the surface of equilibrium coincide along the azeotropic line $X_l = 0$ in P, T plane and are cut off at the critical temperature, $T_{crit}^{(sym)}$, of symmetric system, where $T_{crit}^{(sym)}$ is derived by the following condition

$$\frac{\partial P}{\partial \rho} = \frac{\partial^2 P}{\partial \rho^2} = 0 \qquad (2)$$

taken at $X_l = X_v = 0$.

References

[1] M.Brack, C.Guet and H.-B.Høakansson, Phys. Rep. **123**, 275 (1985).

[2] F.Tondeur, Nucl. Phys. **A315**, 353 (1979).

Surface Instability of a Nuclear Fermi Liquid Drop

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We consider the instability of the incompressible nuclear Fermi-liquid drop with respect to surface distortions. Both the finite size effects and the memory and temperature effects in the collision integral influence strongly the instability growth rate of the nuclear liquid drop [1]. In the present work we study the instability growth rate and the limiting temperature using a simple Fermi liquid drop model with a sharp edge. The drop is incompressible, uniformly charged and has a temperature-dependent surface tension and Coulomb energy. The limiting temperature, T_{lim}, and the transition to an unstable regime are derived from the condition of the disappearance of the stiffness coefficient with respect to the small surface distortion of multipolarity L.

We have found that the instability growth rate, Γ_L, for a certain multipolarity L of the surface distortion is given by

$$\Gamma_L^2 = \Gamma_L^{(LD)^2} - \zeta_L(\Gamma_L) \,, \qquad (1)$$

where $\Gamma_L^{(LD)}$ is the instability growth rate of the classical liquid drop and $\zeta_L(\Gamma_L)$ is the correction due to the Fermi surface distortion effect:

$$\Gamma_L^{(LD)} = \sqrt{|C^{(LD)}|/B_L} \,,$$

$$\zeta_L(\Gamma_L) = \frac{\Gamma_L\,\tau}{1+\Gamma_L\,\tau}\,\frac{d_L\,P_{eq}}{B_L} \,. \qquad (2)$$

Here, the collective mass B_L and the stiffness coefficient $C_L^{(LD)}$ are given by the traditional liquid drop model, τ is the relaxation time, P_{eq} the equilibrium pressure of a Fermi gas, $d_L = 2(L-1)\,(2L+1)R_0^3/L$ and R_0 is the radius of the nucleus. It can be seen from Eq. (1), that the Fermi surface distortion effect (FSDE) reduces significantly the instability growth rate Γ_L with respect to the one, $\Gamma_L^{(LD)}$, given by the liquid drop model. In the rare collision regime $\tau\Gamma_L \to \infty$, the FSDE leads to the threshold behavior of the instability growth rate, Γ_L, with growing L.

The stiffness coefficient $C_L^{(LD)}$ is temperature dependent because of the temperature dependence of both the surface stiffness coefficient b_S and the Coulomb parameter b_C in the liquid drop mass formula. In numerical calculations we used the following approximation from Ref. [2,3]

$$b_S = 17.2\frac{16+C_i}{x_i^{-3}+C_i+(1-x_i)^{-3}} \times$$

$$\times \left(\frac{T_C^2(x_i)-T^2}{T_C^2(x_i)+a(x_i)T^2}\right)^{\nu} \mathrm{MeV} \,,$$

$$b_C = 0.7(1 - x_C T^2)\,\mathrm{MeV}, \qquad (3)$$

where $a(x_i) = a_0 + a_2 y^2 + a_4 y^4$, $y = 0.5 - x_i$, $C_i = 24.4$, $a_0 = 0.935$, $a_2 = -5.1$, $a_4 = -1.1$ and the parameter x_C was chosen as $x_C = 0.76 \cdot 10^{-3}\,\mathrm{MeV}^{-2}$. The surface critical exponent ν was taken as $\nu = 1.25$ and $\nu = 1.5$ and $T_C = 18\,\mathrm{MeV}$ is the critical temperature for infinite nuclear Fermi-liquid. The asymmetry parameter x_i for certain nuclei was taken from