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

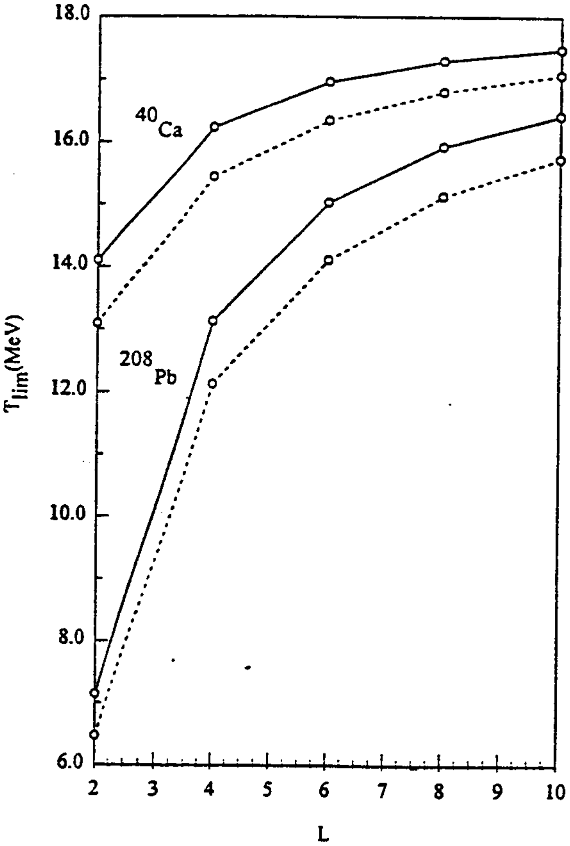

Figure 1. Dependence of the limiting tempetature T_{lim} on the multipolarity L of the surface deformation for the nuclei ^{208}Pb and ^{40}Ca. The solid line is for the critical exponent $\nu = 1.25$ and the dashed line is for $\nu = 1.5$.

[3]. At a certain temperature (limiting temperature, T_{lim}) both the stiffness coefficient $C_L^{(LD)}$ and the instability growth rate Γ_L disappear simultaneously because of Eqs. (1) and (2). So, we define the limiting temperature T_{lim} by the condition $C_L^{(LD)}(T)\Big|_{T=T_{\rm lim}} = 0$. For temperatures $T > T_{lim}$ the nucleus is unstable with respect to surface distortion. The limiting temperature $T_{\rm lim}$ depends on the mass number A and the surface distortion multipolarity L. In Fig. 1 the L-dependence of the $T_{\rm lim}$ is shown for the nuclei ^{208}Pb and ^{40}Ca. An increase of the limiting temperature with L means that the yield of small clusters (high L) caused by the surface instability of the nucleus increases with T. The A-dependence of the limiting temperature $T_{\rm lim}$ for $L = 2$ and $L = 4$ and for two different values of the surface critical exponent ν is plotted in Fig. 2. This A-dependence becomes weaker with increasing L.

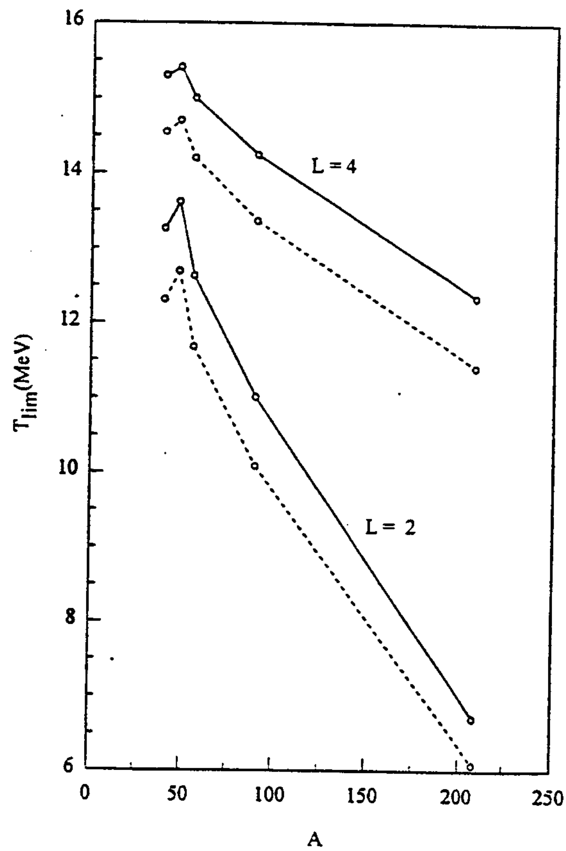

Figure 2. Dependence of the limiting tempetature T_{lim} on the mass number A for the $L = 2$ and $L = 4$ deformations of the nuclear surface. The solid line is for the critical exponent $\nu = 1.25$ and the dashed line is for $\nu = 1.5$.

We point out that Figs. 1 and 2 were obtained within the liquid drop model neglecting the Fermi surface distortion effects. However, as can be seen from Eqs. (1) and (2), the general condition of the development of the instability given by $\Gamma_L = 0$ coincides with the same condition $\Gamma_L^{(LD)} = 0$ for the liquid drop model. Therefore the limiting temperature $T_{\rm lim}$ should be the same in both cases and Fig. 1 and 2 are applicable for the Fermi liquid drop also.

References

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