Stability and instability of a hot and dilute nuclear droplet: dissipative isoscalar modes

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In [1] we have introduced a collective model which allows to study the bulk and surface modes of a nuclear droplet as function of its density ϱ and temperature T. The description is based on the diabatic approach to dissipative collective motion and – in the local density approximation – yields equations of motion for small amplitudes, where the mass and stiffness tensors are obtained analytically. The model is suited to explore systematically characteristic properties of hot nuclear droplets as function of their densities.

In [1] we have studied isoscalar modes in the adiabatic limit, which is defined by a vanishing relaxation time ($\tau = 0$, instantaneous intrinsic equilibration). However, the adiabatic (or thermodynamic) limit is quite unrealistic for nuclear systems, because realistic values for the relaxation time are of the same order as the characteristic times of collective motion in the region of the liquid-gas phase transition. Therefore, we extend our study here to arbitrary values of the relaxation time, and thereby include dissipation.

By varying τ between infinity and zero our diabatic approach allows us to treat the continuous transition between the two elastic limits, *i.e.* the diabatic limit($\tau \to \infty$), where the dynamical distortions of the local Fermi sphere are not destroyed by two-body collisions, and the adiabatic limit ($\tau = 0$), where the Fermi sphere is assumed to be restored instantaneously. When expressed in terms of the temperature, the relaxation time of a Fermi-liquid is practically independent of the density ϱ, yielding rates $\hbar/\tau \approx T^2/3\text{MeV}$. In addition to the adiabatic spinodal we find also diabatic spinodals for the bulk modes of infinite nuclear matter and nuclear droplets, however not for surface modes.

As discussed in [1], the eigenvalue equation for the collective modes in harmonic approximation reads (eq. (1.19))

$$-B_{\lambda\lambda'}\,\omega^2 + C'_{\lambda\lambda'}\frac{\omega}{\omega + i/\tau} + \overline{C}_{\lambda\lambda'} = 0 \qquad (1)$$

with the mass tensor $\mathbb{B} \equiv \{B_{\lambda\lambda'}\}$, the adiabatic stiffness tensor $\overline{\mathbb{C}} \equiv \{\overline{C}_{\lambda\lambda'}\}$ and $\mathbb{C}' = \mathbb{C} - \overline{\mathbb{C}}$ the difference between the diabatic ($\mathbb{C}$) and adiabatic stiffness tensors.

Since the secular equation for the eigenmode energies is of third order, there exist three roots (for each eigenmode) for $0 < \tau < \infty$ instead of two for the adiabatic and diabatic limits. As functions of τ the eigenvalues move around in the complex ω-plane on generic trajectories which depend on the positions in the (ϱ, T)-plane. The main effects of dissipation as compared to the adiabatic limit are summarized as follows.

- The spinodal lines for bulk and surface modes are not changed by dissipation.

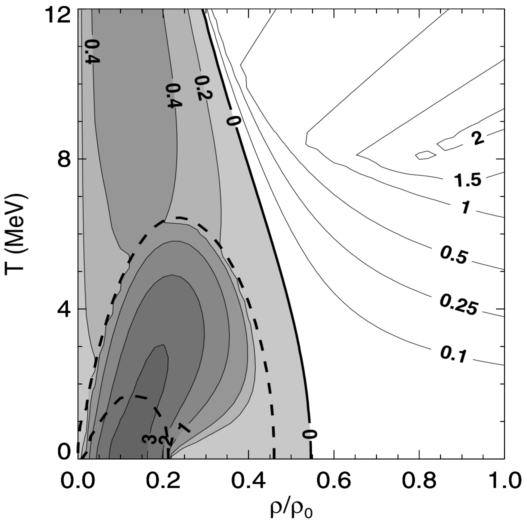

Figure 1: *Combined bulk and surface instabilities (soft EOS) for a gold-like droplet. Shown are the largest growth rates (shaded areas) and the smallest vibrational damping rates in MeV. The dashed lines indicate the adiabatic and diabatic bulk spinodals.*

- However, the growth rates of unstable bulk and surface modes are quite sensitive to dissipation and, due to the sensitivity of the relaxation time τ on temperature T, are reduced from their adiabatic values by factors 1/2 to 1/4 in the region of interest.
- The qualitative differences between soft and stiff equations of state (EOS), with larger spinodal regions and larger growth rates for the stiff EOS, survive, when dissipation is included.
- Dissipation leads to some increase in the splitting of growth rates for modes with different multipolarities l and number n of radial nodes. With decreasing density the quadrupole mode $l, n = 2, 0$ becomes unstable first, followed in sequence by the higher multipoles $l = 3, 4, 5$ and nodal number $n = 1, 2$.

The results show that the qualitative features of multifragmentation by spinodal decomposition survive when dissipation is included. During the clustering process thermalization within the decaying droplet is so fast (relaxation time $\tau \approx 20$ fm/c for $T \approx 5$ MeV) that statistical equilibrium is attained throughout the formation of fragments. This explains why statistical models are so successful in describing various aspects of multifragmentation.

References

[1] W. Nörenberg, G. Papp and P. Rozmej, Eur. Phys. J. A **9**, 327 (2000), GSI Scientific Report 2000.

[2] W. Nörenberg, G. Papp and P. Rozmej, Eur. Phys. J. A (2002, in press), arXiv:nucl-th/0201022.

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