Thermal coupling between two liquid films undergoing long-wavelength instabilities

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In this study the effects of coupling between two self-organizing systems are analyzed. Two thin liquid films are placed opposite to each other on flat substrates, which are maintained at different temperatures T_1 (lower substrate) and T_2. The films are separated by a gaseous layer and affected by thermocapillary and gravitational stresses. Without the presence of the respective other film, in previous works it has been shown that if $T_1 > T_2$ the upper film undergoes a long-wave thermocapillarity-stabilized Rayleigh-Taylor (RT) instability while the lower one is susceptible to a long-wave gravity-stabilized Bénard-Marangoni (BM) instability [1–3]. Inspired by [4], the thermal coupling between these two instabilities is analyzed at hand of the triple layer configuration schematically shown in Fig. 1.

The deformation of one film changes the surface temperature of the other one, altering the thermocapillary forces along its interface. Since the viscosity of the gaseous medium can be neglected, there is no direct mechanical connection between the liquids. This simplifies the analysis, as the evolution equation of the film height used in systems with one liquid layer can be directly applied, and the coupling only needs to be considered in the energy equations.

In the analysis it was assumed that the liquids have identical material properties and similar initial thicknesses. Full numerical calculations and a linear stability analysis of the evolution equations were conducted. In comparison to the individual systems investigated before, it has been found that the coupling changes the stability properties of the system. Depending on the dimensionless groups of the films, regimes with different degrees of coupling were identified. In those with weaker coupling, only one of the films is inherently unstable, while triggering a deformation also in the stable one. In regimes with stronger coupling the joint system may be stable, but within a certain parameter range a qualitatively different instability appears on both surfaces where the emerging patterns undergo lateral movement (Fig. 2). It can be shown that such behavior cannot occur for the isolated RT and BM instabilities. The numerical simulations of the non-linear evolution equations agree well with the analytical predictions. In essence, equivalent to the circumstance that the coherent behavior of a single self-organizing system is more than just the sum of the individual properties characterizing the isolated building blocks, it is found that the coupled system has considerably enhanced properties compared to the individual systems.

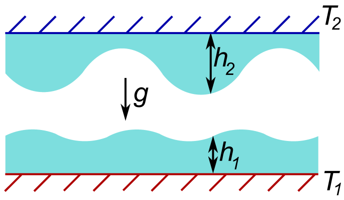

FIG. 1: Two thermally coupled liquid films under the influence of gravity and thermocapillarity.

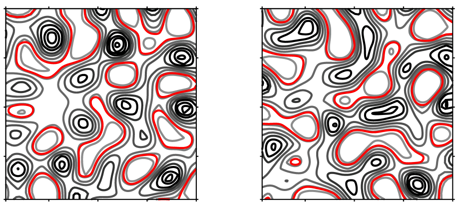

FIG. 2: Contour plots of the pattern on the lower liquid film at two consecutive timesteps with highlighted contours at a selected liquid thickness.

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