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Freezing processes in atmosphere and polar ocean

B. Kutschan[1], S. Thoms[2]
[1]FH Münster, Germany, kutschan@fh-muenster.de
[2]AWI Bremerhaven, Silke.Thoms@awi.de

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Pattern formation in living matter but also in inanimate matter as well as the creation of snow and ice crystals, dendrites or needles are always out of equilibrium and "between the world of living and the world of inanimate, there is a difference of complexity, not of nature" asserts JACOB cited by PELCÉ.

A special role during the pattern formation play kink solutions that represent the different state of order at the phase boundaries. They are basic components for pattern formation in one and multi-dimensional systems, whereby in two and three-dimensional spaces the number of degrees of freedom increase in each case. The mechanisms of the kink formation can give an insight into the dynamics of phase transitions.

A general approach for pattern formation during phase transitions is given by the time dependent Landau-Ginzburg theory, which describes the phase transition in terms of an order parameter. The driving forces of the phase transitions are based on the nonlinearities of the polynomial functions in the order parameter. By varying the Landau free energy, we obtain an Euler-Lagrange equation with multiple solutions in the time-independent case. At the phase transition the ordered as well as the disordered state have the same free energy, this means that the double-well potential is symmetrical and degenerate, i.e. each of the two minima of equal depth lies on a double real zero. Only under these conditions can a kink or antikink arise as a non-dissipative solution for which the energy density does not vanish. For this special case, a wave equation for the kink can be derived and therefore a propagation speed of the wave front (phase boundary) can be determined analytically, because a fixed phase relationship exists. A translation of a kink symbolising the phase boundary does not change its shape, because the energy density at the phase boundary, represented by a kink, is preserved due to the symmetry of the double-well potential. It concerns out-of-equilibrium growth forms, because during the temporal evolution the free energy changes and runs into a minimum at constant temperature. From the solution of the time dependent Landau Ginzburg theory we get diverse morphological structures. A steady state as a bridge between the classical nucleation theory and the phase field theory is discussed. The nucleation and growth process are coupled by two fields, the nucleation- and the growth field. If a kink and an antikink move away from each other, this is called a freezing or growth process and the influence of the nucleation field disappears more and more. The nucleation and growth field are connected by a parabola, a conic section, which can be seen as a limiting case between bound and unbound state.

The crystal growth process is modified by ice bindig (antifreeze) proteins of microorganisms, that colonise the sea ice and change its morphology. For example the diatom species Fragilariopsis cylindrus produces antifreeze proteins (AFPs) of moderate thermal hysteresis.

REFERENCES

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