Dynamical scaling laws – A few unanswered questions

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Abstract. When a system with continuous symmetry is quenched instantly to a broken symmetry state, topological defects appear in an otherwise homogeneous medium of continuous symmetry. Further growth of the topological defects are of continuous nature such that the time evolution of the system can be described by Ginzburg–Landau free energy functionals.

The phenomenon of new phase formation is a representative example of first-order transition. The phenomenon is fundamental and of immense interest as an example of a highly nonlinear process far from equilibrium. The second phase grows with time and in later stages all domain sizes are much larger than all microscopic lengths. In the large time limit, the new phase-forming systems exhibit self-similar growth pattern with dilation symmetry, with time-dependent scale, and scaling phenomenon. The phenomenon is indicative of the emergence of a morphological pattern of the domains at earlier times looking statistically similar to a pattern at later times apart from the global change of scale implied by the growth of time-dependent characteristic length scale $L(t)$ – a measure of the time-dependent domain size of the new phase.

The scaling hypothesis assumes the existence of a single characteristic length scale $L(t)$ such that the domain sizes and their spatial correlation are time invariant when the lengths are scaled by $L(t)$. Quantitatively, for isotropic systems, the equal-time spatio-temporal composition modulation autocorrelation function $g(r,t)$, which reflects the way in which the mean density of the medium varies as a function of distance from a given point, should exhibit the scaling form with time-dependent dilation symmetry

$$g(r,t) = f(r/L(t)).$$

The scaling function $f(r/L(t))$ is universal in the sense that it is independent of initial conditions and also interactions as long as they are short ranged. However, form of $f(r/L(t))$ depends non-trivially on n, the number of components in the vector order-parameter field exhibiting the scaling behaviour, and d, the dimensionality of the system. It is important to note that the scaling hypothesis has not been proved conclusively except for some model systems.

The Fourier transform of $g(r,t)$, the structure factor or scattering function $S(q,t)$ for a d dimensional Euclidean system, obeys simple scaling ansatz at later times,

$$S(q,t) = L(t)^d F(qL(t)).$$

Based on some of our recent observations on phase separation of a multicomponent alloy involving hydration of cementitious material, it is proposed to discuss some unanswered questions pertinent to the validity of dynamical scaling laws addressing some issues like (i) uniqueness of characteristic length $L(t)$, (ii) the extent of validity of the scaling laws for new phase formation in the case of non-Euclidean fractal systems, (iii) the extent of validity of the scaling laws for multicomponent systems.

The need for investigations examining the extent and the nature of the validity of the scaling laws for confined systems and for systems subjected to random field will also be discussed.

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