Glass transition as a topological phase transition

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The microscopic mechanisms that give rise to the glassy state of matter are still the subject of debate. In particular, it remains a debatable question: whether glasses can be considered as ultimate viscous liquids, or the glass phase is a result of a true thermodynamic phase transition to the solid state [1]. The presented work argues in favour of the second statement and shows that the transition to the glass phase can be fully described as a phase transition in a system of topological defects, i.e., as a topological phase transition.

This approach is not new. The theoretical description of the glass phase as a frozen system of topologically stable defects was actively developed at the end of the last century (see, for example, [2,3]). At that time, it was suggested that the transition to the glassy state is a topological phase transition [4]. In the presented work, a development of this approach is proposed.

It is shown that in the three-dimensional system of topological defects the phase transition can occur, the description of which is reduced to a simple model with the effective Hamiltonian of effective (gauge) field describing the interaction between topological defects [5,6]. Such a system is characterized by the presence of two spatial scales: the interaction radius, which is inversely proportional to the gauge field mass, and the correlation length of topological defects, which grows much faster than the interaction radius as the system approaches to the topological phase transition point. Using methods of nonequilibrium (critical) dynamics it is shown that the correlation length is proportional to the relaxation time, which divergence is described by the Vogel-Fulcher-Tammann law, and the glass transition temperature depends on the cooling rate [5,6]. The theory reproduces the most of characteristic thermodynamic and kinetic properties of glass transition: the behaviour of susceptibility, and non-linear susceptibilities; heat capacity behaviour; and ``boson peak'' near the glass transition temperature.

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