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Opinion

Analogies in Polymer Physics

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Opinion

Traditional methods for describing long polymer chains are so different from classical solid-state physics methods that it is difficult for scientists from different fields to find a common language. When I reported on my first work on polymer physics at a general physical seminar, Academician Ginzburg (not yet a Nobel laureate) got up and left the room: "This is not physics". "Phew, what a nasty thing!"-this was a short commentary on another polymer work of the well-known theoretical physicist in the solid-state field. Of course, practical needs and the very time have somewhat changed the attitude towards the physics of polymers. But even now, the best way to bury your work in polymer physics is to directly use the methods and slang of other areas of physics.

Over the past fifty years, the methods of physics have changed a lot. New ideas, packaged in elegant (or not so) analytical formulas, are replaced by the charts generated by computer simulations for carefully selected system parameters. People have learned to simulate anything if they can allocate enough money for new computer clusters. But unfortunately, this does not always give a deeper understanding of physics, for which it is traditionally sufficient to formulate a simplified model of a "spherical horse in a vacuum". Complicate is simple, simplify is difficult, as Meyer's law states. But it would be good to remember that everything we do is different sides of the same Physics.

And then - what a surprise! - it turns out that the mechanisms that control many processes from different fields of physics are the same. The use of analogies and methods from different fields gives a huge impetus to the development of polymer physics. Edwards realized that one can apply the field theory methods outside particle physics to solve many complex problems in polymer physics [1]. It turns out that even the purely polymer problem of taking into account topological interactions due to the uncrossability of polymer chains can be solved by analogy with the movement of a quantum charged particle around a wire with the current [2]. As shown by De Gennes, the classical problem of the conformations of a polymer chain, the monomer units of which interact with each other due to the presence of excluded volume, can be solved by using the polymer-magnet analogy [3].

And this was only the beginning of the insidious penetration of general physical methods for the description of polymers. The conformations of the polymer chain in a random medium are found by analogy with the Anderson electron localization [4]. For averaging over the disorder, the mysterious replica method is used here, the physical meaning of which, as well as the area of applicability, remains unclear until now. Branched polymers did not stand aside, each of their configurations can be associated with the corresponding Feynman diagram of some nonlinear quantum field theory [5]. And instead of painstakingly calculating the symmetry indices of polymer molecules, simple (for those who understand!) and universal methods of quantum field theory begin to work for us.

In a system of branched polymer molecules, a purely topological gel-sol transition can occur. Such a "percolation" transition does not belong to phase transitions that are so

customary and discussed in statistical physics since in this case, no thermodynamic quantities have singularities. However, this transition can also be described by the Potts model, well-known in statistical physics [6].

Polymer networks have a new physical property-elasticity, which substantially depends on their structure-the order of crosslinking of polymer chains. Classical polymer methods allow one to describe the elasticity of polymer networks only in a model assuming a tree structure of networks. Real polymer networks consist of a huge number of overlapping and interconnected polymer loops. Also, due to the randomness of the crosslinking process, the structure of polymer networks is random. Therefore, to describe them, it is natural to use the replica method, which allows one to calculate the elasticity of such polymer networks with loops and numerous defects of the topological structure [7,8].

Of particular interest in statistical physics and quantum field theory is the study of strongly fluctuating systems near the second-order phase transitions. To describe the "critical" fluctuations at different spatial scales in such systems, the renormalization group method was developed. Of course, polymer physics could not pass by such achievements! But in order not to frighten people, the words "renormalization group" were replaced by "scaling", and the Gell-Mann-Low equations were replaced by "blobs", from which, as from the original monomer units, polymer chains are assembled [9,10]. You should have seen the huge eyes of physicists in quantum field theory, to whom such exciting scaling concepts are reported!.

An interesting observation was made in the study of phase transitions from a disordered phase to a periodic crystal-like lattice. It turns out that the presence of a finite wave vector of the emerging superstructure suppresses fluctuations in such a system. Not surprisingly, this observation caused an avalanche of works on the theory of microphase separation in polymers, which continues even today [11].

Of course, unexpected analogies from other fields that can be adapted to describe polymers are not limited by the above list. Everyone can find something interesting. The main thing is not to forget that according to Murphy's law "Everything is part of a larger system". And this system is called Physics.

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