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Book Review: *Statistical Physics of Polymers*

Statistical Physics of Polymers. T. Kawakatsu, Springer, Berlin, 2004.

There is no shortage of books on polymer physics. Many of them very good. In writing yet another one, the prospective author should thus have a firm vision why his or her book would be picked up by the prospective reader when compared to all the other ones available on the market. This particular book, that grew out of a series of lectures for graduate students given by Prof. Toshihiro Kawakatsu at several universities in Japan, was conceived as an introduction to the concepts as well as theoretical methods used in contemporary research in the physics of polymers and complex fluids. It is built around simple but essential examples of mesoscale behavior of polymers taken from various areas of polymer physics that illustrate these concepts as well as advanced statistical mechanical methods used in polymer science.

This book thus avoids the consistent use of the more popular scaling approach, though it of course contains also scaling analyses, in favor of an introduction to a more varied choice of methods used in advanced polymer science, such as path integral approach, self-consistent field methods and the Ginzburg-Landau theory. It is mostly a fortunate blend of depth and breadth, relatively readable and in general self contained. The author uses a two-tier system where some more technical and/or mathematical concepts, equations or derivations are relegated to separately marked (grey) parts of the text. The reader is thus coached through some technical intricacies or can even skip them altogether on first reading. I personally find the two or even three tier system quite helpful since it introduces an additional classification of the presented material that is usually only hinted at in the main division of the book into chapters.

The subject matter of the book is divided into five chapters and covers Gaussian chain models and statistics of polymers, mesoscopic structures and self-consistent field theory, the Ginzburg-Landau theory and the macroscopic viscoelastic theory of polymers. In each of these chapters the author presents important concepts as well as introduces various statistical mechanical methods that are frequently used in polymer physics. This is achieved by a thoughtful choice of illuminating examples that allow for conceptual as well as formal advances throughout the book. Though in general the book is self-contained there are some

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derivations that dangle in the air or are not as esthetically appealing as most of the rest. One needs to realize and acknowledge however, that it is often more difficult to write a readable compendium of methods then just an introduction to the concepts of any field. All in all the book fares quite well in its difficult undertaking and should be quite helpful for anybody teaching a course on polymer physics to advanced graduate students.

The introductory chapter takes the reader on a grand and concise tour of complex fluid phenomenology that ends up in the phenomenology of polymer structure and modeling. Maybe this chapter is a bit terse and an interested reader will need to broaden his or her knowledge of polymer phenomenology from other books where more space is devoted to pure phenomenology. The second chapter then paves the way to Gaussian chain models and general statistics of polymer chains. Lattice polymer chain models are explained in order to introduce the concept of polymer configurations, the random walk model and the excluded volume effects. Lattice chain models are furtheron used to derive statistical properties of an ideal polymer chain that culminate in a thorough derivation of the end-to-end vector underpinned by some basic concepts of the probability theory. The formal part of this derivation is mathematically clear and thorough. Some intermediate calculus is however needed in order to follow the derivations throughout the book, though advanced mathematical concepts and formulas are usually explained in the grey parts of the text. From lattice models we then move on to continuum bead-spring models, Gaussian chain statistics and fractal nature of polymer chain statistics. All these advances nicely converge on the introduction of the correlation functions and polymer scattering experiments. Next follows the treatment of non-ideal chains which is used to introduce the mean-field and the perturbation theories. The non-ideality is then further analysed in the context of many chains via the Flory-Huggins theory. The treatment of the dynamics of the polymer chains is next. Brownian motion and the Rouse model, both introduced very thoroughly, pave the way to hydrodynamic effects, the Oseen tensor and the Zimm model. This whole chapter is completely self-contained and a delight to read. It uses just the right mixture of formal rigor and clearness. The Kuhn's model is next used to justify the Gaussian chain model and to introduce some recent advances in experimental techniques such as laser tweezers and fluorescence microscopy applied to DNA and actin filament elasticity. The chapter concludes with a short introduction to molecular simulation of polymer dynamics.

The next chapter deals with mesoscopic polymer structures and introduces the self-consistent field theory. It is derived from the path integral formalism as applied to polymer statistical mechanics. The path integrals are introduced on a level that is both understandable and relatively easy to follow via their connection with quantum mechanics. The classical or saddle point approximation is then derived and used in the context of polymer brushes, where the thermal fluctuation effects are assumed to be small. Unfortunately I find the treatment of polymer brushes that follows difficult to decipher in all its details. Some results are just stated and I do not think that it would be so difficult to derive them explicitly. It would add much to the elegantly conceived chapter if these derivations were made explicit. Next follow the numerical methods for the solution of the self-consistent field theory. This is a very technical and in general difficult subject but I find the discussion in the book very concise and self-contained. One really bothering thing in this and the following chapters is the size of indices which are of the same size as the indexed symbols. This is extremely annoying and makes the equations very awkward looking and in general difficult to absorb in a single glance. It is tough to find one's way through these already complicated equations where it is difficult to differentiate between the indices and the indexed quantities. After the setting of the stage the authors goes through a short introduction to the real-space, reciprocal lattice calculations and dynamical simulations of the self-consistent field theory. Then follows a more detailed description of numerical examples of the general theory centered around mesoscopic structures in block copolymer systems. The phases in the rich phase diagram of the block copolymers are then used to introduce the concept of curvature and bending energy. None of the chapters are exhaustive in its subject matter. They introduce just enough of it to introduce a new concept or to illuminate a new method.

The Landau-Ginzburg theory in the next chapter is introduced via its relation to the self-consistent field theory. The expansion of the free energy is derived quite thoroughly and is used also as an introduction to the linear response theory and the definition of the cumulant expansion. The random phase approximation is then introduced and used to calculate the relevant correlation functions. The Flory-Huggins-de Gennes functional is next used to illustrate some of the general properties of the Landau-Ginzburg theories. The phase diagram of of block copolymer melts is finally described as an application of the Landau-Ginzburg theory. In this whole chapter the derivations are somewhat terse, not really self-contained, and regrettably are sometimes quite difficult to follow, not least because of the awkward size of the various indices and symbols. I believe that this chapter is amopng the least exhaustive in the whole book and would have to be substantially expanded and rewritten in order to be really readable not to say anything about intelligible.

The last chapter is devoted to the macroscopic viscoelastic theory of polymers. The phenomenology of viscoelasticity is first introduced via the loss and storage moduli and its simple hydrodynamic description in terms of various viscoelastic models. Next follows a very nicely written introduction to reptation theory which is used to derive the frequency dependence of both viscoelastic moduli. The stress relaxation function is introduced and its Green function is explicitly derived but most of the discussion of the extensions of the simple reptation theory via contour length fluctuations and constraint release is dealt with very briefly mostly on the descriptive level. This chapter too would benefit if it would be more exhaustive and if it would contain enough formalism at the same level as e.g. the second chapter which in my opinion seems to be the best (and the longest) and the most exhaustive in the whole book.

All in all this is an interesting and useful book. Some of it is very readable and absolutely perfect for a graduate course on polymer physics since the chapters even come with a short list of illuminating simple problems. This would be a course that gives equal weight to concepts as well as an introduction to a slew of various methods pertinent to polymer physics or soft matter in general. It would thus allow the students to see a bit beyond the scaling approach as masterfully wielded in the able hands of many authors. Unfortunately some parts of this book are not very self-contained and difficult to follow. Also the level of detail seems to be uneven from chapter to chapter. A few of the chapters would need to be expanded significantly in order to match the readability and conciseness of the e.g. second chapter. Nevertheless this book seems to be almost a perfect basis for an advanced graduate course of polymer physics and I would certainly recommend it as such.

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