Quiz 7 Polymer Physics February 28, 2020

K. K. Bejagam, Y. An, S. Singh, S. A. Deshmukh, *Machine-Learning Enabled New Insights into the Coil-to-Globule Transition of Thermosensitive Polymers Using a Coarse-Grained Model.* (J. Phys. Chem. Lett. 2018, 9, 6480–6488) developed coarse-grained simulations of PNIPAM (poly(N-isopropylacrylamide)) to observe the coil-to-globule transition. Coarse-grained simulations involve clustering atoms into balls. The interaction potential of the balls is determined either analytically or in this case by molecular dynamics simulations. Bejagam uses machine-learning to speed up the simulation. In this case he uses experimental data and has his coarse-grained simulation learn to match the results of these experiments such as the LCST temperature and the measured coil size. The code self-modifies to replicate the experimental results (some might call this a form of cheating).



- a) The coil-to-globule transition was modeled by Grosberg as discussed in class (and explained in the small book *Giant Molecules*). Give a coarse-grained explanation of Grosberg's model compared to the Flory-Krigbaum model. How does this lead to a prediction of coil collapse?
- b) The plots above are for N = 5, 18, 30 and 100 mer polymer chains. The red curves are in the globule state (3-d) and the black curves are in the coil state (2-d). Make a table of the observed maximum R_g for the red (globule) and black (coil) curves. Take the ratio of these estimated R_g s and compare those ratios to the expected ratios for coil ($d_f = 2$) and globule ($d_f = 3$) based on the chain scaling and N = 5, 18, 30 and 100. Make a plot of the simulated ratio vs. the expected ratio.

- c) The distribution curves in (e) and (f) show bimodal behavior below the LCST (coil state, black) with one mode that seems to be collapsed (smaller R_g). Bejagam explains this by starting the simulation in different conformational states and noticing that the result in terms of these modes changes. Coarse graining allows for long simulations, these simulations run for about one micro-second (10⁻⁶ s), the molecular dynamics simulations for the beads last for about 2 femtoseconds (10⁻¹⁵ s). Comment on these two modes that are seen in graphs (e) and (f).
- d) Plot (d) is for the 5-mer chain. Explain the observed behavior.
- e) Below are plots of R_g versus temperature for different starting chain conformations. The curves show that the coil to globule transition occurs at different temperatures for different starting chain conformations. Do you think that this is a first order or a second order transition? (In your argument, describe first and second order transitions in this context.)



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$$F(\alpha) \sim kT(\alpha^2 + \alpha^{-2}) + \frac{kTBz^{1/2}}{2\alpha^3 l^3} + \frac{kTC}{\alpha^6 l}$$

1.2

 $\alpha^{2} \alpha^{3} l^{3} \alpha^{6} l^{6} \alpha^{2}$ and α^{3} terms are from FK. The α^{2} term is associated with the number of 3d blobs, z/g^{*} , and that each blob has kT energy. The last term is an attractive term for ternary interactions that leads to phase separation. Setting the derivative of this free energy to 0 and finding the minima leads to a phase diagram with a first order transition between collapsed globules and expanded coils which is controlled by the ratio of C/B, third and second virial coefficients.

U) IV Agglobule Ag,coil Katlo IV	$\frac{1}{2}/1$ $\frac{1}{10}$ - 1 $\frac{1}{10}$
(Red) (Black) B/R	
5 5.05 5 0.99	1.31
18 10.5 12.5 1.2	1.62
30 11.5 16.7 1.45	1.76
100 15 13 0.87	2.15
2.0	
1.8 -	
16	
9	
m 1.2 -	

Except for the last point it doesn't look too bad. On the other hand, with the Machine Learning (aka cheating) it should have a perfect answer, i.e. straight line with increasing slope.

- c) The two modes seem to be an artifact of the short equilibration time. On the other hand they could indicate that the simulation doesn't work. Until computers can simulate on the order of seconds we will probably never know.
- d) Bejagam claims that others have found that you can't get coil collapse for a 5-mer. The point in the graph isn't that far off from a straight line except for the last point which may have problems with equilibration. Long chains take much longer to reach equilibrium. Generally, fractal scaling is used when you have orders of magnitude differences in size from monomer to chain, so at least 10 say. He has a reasonable point.
- e) First order would be a sharp change at the LCST. The middle curve seems to show that. The first curve doesn't seem to be a transition at all within the error bars. The last curve looks like a second order transition. Bejagam's intent is to show a first order transition, I would say that he hasn't convincingly achieved that goal.