

3.052 Nanomechanics of Materials and Biomaterials : Spring 2007 Optional Midterm Exam Due : Wed 04/04 Midnight

Instructions : This exam is based on Seitz, et al. *Langmuir* 2001 4616-4626. Please do not copy sentences or phrases directly from this paper as a response to test questions - no credit will be given. Everything must be answered in your own words. This exam is "open book" but you will not need to read the full paper or do additional research to answer the questions below. The questions are based on the course/lecture content. Important: This exam is non-collaborative on the honor system, i.e. you must work by yourself on it and not consult with your classmates or anyone else.

Figure 1a is a schematic of a nanomechanics experiment using the surface force apparatus (SFA) to measure the interaction between two polymer-supported lipid bilayers. Figure 1b is the nanomechanics data on approach (Force/Radius vs Distance) where "Radius" is the radius of each cylindrical surface (~ 1.5 cm). The experiments were performed in aqueous electrolyte solution.

1. Describe in one paragraph (no more than 0.5 page) one potential method for quantitatively verifying the success of the surface functionalization scheme observed in Figure 1a via AFM imaging (*hint* : one can not just AFM image the SFA mica surfaces).

2. General Questions on Figure 1b.

- (i) At what approximate surface separation distance do the tops of the lipid bilayers on each surface make physical contact and touch each other? Why?
- (ii) In the podcast by Higgins, et al., the authors claimed to see oscillatory forces due to structured water at the lipid bilayer surface. In what region would you expect for these oscillations to take place in Figure 1b? What is one potential reason for why oscillations aren't observed in this experiment?
- (iii) The SFA uses an interferometry method for measuring absolute values of surface separation distance (as opposed to AFM which is typically relative and relies on the setting the infinite slope regime to $D=0$). This fact is evident from the data in Figure 1b since the infinite slope regime is not at $D=0$ but instead at $\sim D=10$ nm. What does this length scale, 10 nm, correspond to physically in the experiment?
- (iv) Explain how each region of the Force-Distance curve (I, II, III) in Figure 1b would change if the underlying PEI layers were removed from each surface and instead there was only lipid bilayers on mica.
- (v) The experimentally measured adhesive Force/Radius on retract (*data not shown*) was determined to be 0.4 mN/m and adhesion distance was ~ 3 nm. Estimate the Hamaker constant. Is this a reasonable value for van der Waals interactions?

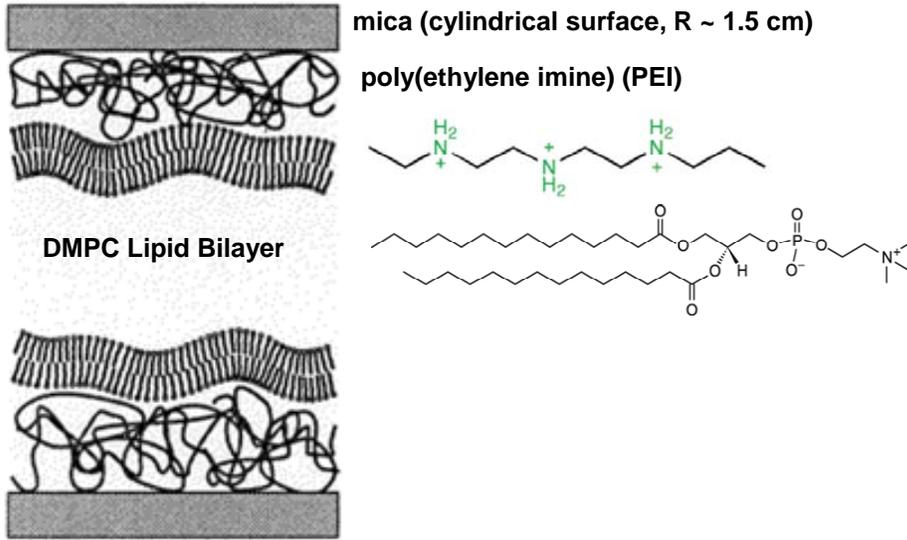
3. Questions on Region (II) of Figure 1b.

- (i) Region II shows that compression of the polymer (PEI) layers results in a repulsive force. What are *two molecular origins* of this repulsive force?
- (ii) Which is stiffer; the PEI layer or lipid bilayer? Why?
- (iii) Calculate the total energy required to compress the polymer layers in region II of Figure 1b from the experimental data.
- (iv) In the paper, the authors used a simple spring model to fit the data in region II. From the model they were able to extract an effective Young's modulus for the network: $E_{\text{eff}} = 47 \times 10^3 \text{ N m}^{-2}$. A different model that could be employed is a rubber elastic network of Gaussian freely-jointed chains. Calculate the deformation energy of both polymer layers using this model assuming uniaxial compression, constant volume deformation, and a Poisson's ratio of 0.5 which infers that : $G_0 = \frac{E}{2(1+\nu)} = \frac{E}{3}$.

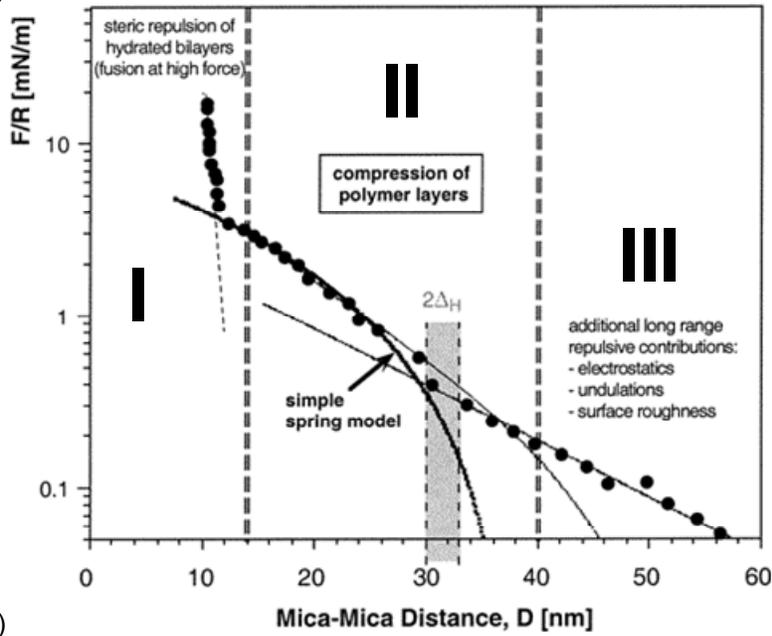
Note: an approximately circular contact region between layers in the SFA was $\sim 20 \mu\text{m}$ in diameter.

- (v) Comment on the differences between the Gaussian freely-jointed chain rubber elasticity model and the polymeric system shown in Figure 1a.

Figure 1.



(a)



(b)