

3.052 Nanomechanics of Materials and Biomaterials : Spring 2007 Assignment #1

Due Date : Tuesday 02.20.07

Feel free to use additional resources (e.g. journal papers, internet, etc.) but **please cite them** (points will be deducted for not doing so). You will need to research additional sources to answer some questions.

1. In Richard Feynman's Lectures "*There's Plenty of Room at the Bottom*" 1959 (Course Reader Document #2) and "*Tiny Machines*" (1984) he asserts that all of the knowledge of humanity (textual knowledge at the time of his lecture) can be stored in a volume the size of the smallest dust particle.

- Follow his assumptions and do this calculation based on the data he provides from 1959.
- Suppose you wanted to use DNA to store all of the textual knowledge of humanity (in 1959), could it theoretically fit within a cell nucleus (assuming 1 base pair = 1 bit)?
- Why can't the internal combustion engine (as it is designed to work macroscopically) scale down to a "tiny machine"?
- Feynman says that his game is "imagination in a tight straitjacket." What does he mean by that?

2. Aggrecan is a very unique "bottle-brush" macromolecule that is largely responsible for the mechanical properties and health of cartilage tissue in our joints (later on in the semester you will hear a podcast with Professor Alan Grodzinsky on this topic). Aggrecan is composed of highly negatively charged polysaccharides called glycosaminoglycans or GAGs (contour length ~ 40 nm) as side chains that are densely packed along a core protein (contour length ~ 400 nm). Aggrecan was chemically end-attached to a planar substrate and a micron-sized probe tip at the end of a microfabricated cantilever at a packing density of 25 nm × 25 nm square per aggrecan molecule. A high resolution force spectroscopy experiment was then carried out where the surfaces were compressed and held for a period of time between the approach and retract curves (*Figure 1* - real data taken in the month!). The uncompressed and compressed height H of the two aggrecan layers are 409 nm and 150 nm, respectively.

- Calculate the net adhesion energy in units of femtoJoules.
- Calculate the average adhesion energy per pair of aggrecan molecules in attoJoules).
- Explain the reason(s) for the "jagged" appearance of the adhesion profile?
- Research and list 3 possible molecular origins of the measured adhesion.

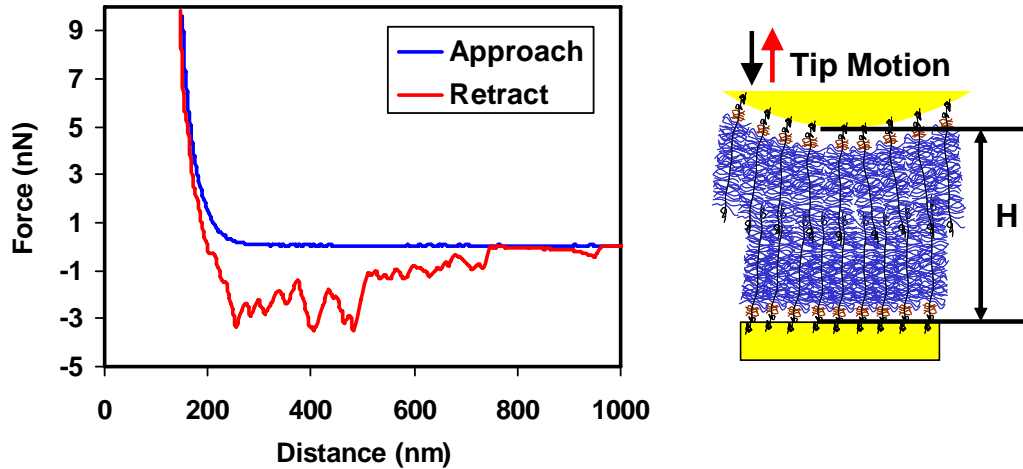


Figure 1. High resolution force spectroscopy experiment; aggrecan vs. aggrecan.

3. Podcast questions : Lipid Bilayer Formation (Recording date 01/16/07)

Guest: Professor Jurgen Fritz (International University Bremen; soon to be Jacobs University Bremen, Germany)

Citation : Pera, I. & Fritz, J. Sensing lipid bilayer formation and expansion with a microfabricated cantilever array. *Langmuir*. 23, 1543-1547 (2007).

- a. Why did Pera and Fritz add cholesterol to some of their DOPC bilayers? Look up and cite specific references for their explanation.
- b. Explain the differences between Figure 2(a) and Figure 2(b) below defining all terms appropriately. Which is more physiologically relevant and which did Fritz say he preferred in physical experiments? What is the purpose of the short molecules depicted in the schematics?

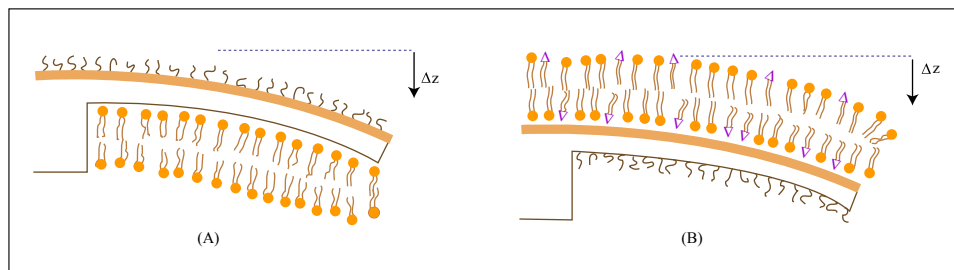


Figure by MIT OCW.

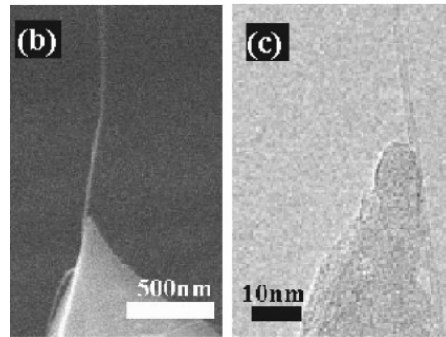
Figure 2 Schematics of lipid bilayer adsorption onto microfabricated cantilevers

- c. Using a cantilever beam with a rectangular cross section, derive the Stony Formula in Pera, et al. 2007;

$$\Delta\sigma = \frac{Et^2}{3(1-\nu)l^2} \Delta z$$

where : $\Delta\sigma$ = surface stress, elasticity modulus, E, thickness of the cantilever, t, Poisson ratio, ν , Δz = cantilever bending, and l = cantilever length. (*This question assumes you are familiar with the basics of beam bending from 3.032 and utilizes equations derived last semester in Lecture; for a review of beam bending see documents posted under Supplementary Resources on the website for Lecture #2.)

4. In Lecture 2 "carbon nanotube probe tips" were discussed briefly



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Figure 3. Yenilmez, et al. *Applied Phys. Lett.* 80, 12 2002 2225

- a. Using typical forces that can be exerted and measured by microfabricated cantilevers and typical dimensions of carbon nanotubes attached to probe tips (cite references), calculate (using Euler's formulation) whether it is theoretically possible to induce buckling in a carbon nanotube probe tip on approach in a high resolution force spectroscopy (HRFS) experiment? State the deficiencies of your assumptions.
- b. What would expect to be the difference between a HRFS on a single cell surface using a carbon nanotube probe tip compared to a regular microfabricated cantilever probe tip? Explain the expected deformation for each case. Do you think there be any advantage to using a carbon nanotube probe tip? (*This question assumes you are familiar with the basics of buckling from 3.032 and utilizes equations derived last semester in Lecture; for a review of buckling see documents posted under Supplementary Resources on the MIT Server website for Lecture #2.)