3.052 Nanomechanics of Materials and Biomaterials : Spring 2007
Assignment #2

Due Date : Tuesday 03.06.07
You are encouraged 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. An excellent resource is SciFinder

1. **Piezos :**

a. Monolithic z-tube scanners operate on the "transversal piezo effect." Explain what this means.

b. Would you be able to quantitatively measure the height of the rabies virus adsorbed on a surface using AFM imaging if you were using a piezo tube scanner with the following properties (d_{31}=-1.73 Å/V, d = 0.5588 mm, L_o=12.7 mm) and a voltage range of +18V to -18V?

c. A new 3-axis nanopositioner has been designed by *Asylum Research, Inc.* for their 3D nanomechanics instrument called the "Molecular Force Probe," as detailed in the "Introduction to AFM" movie you were assigned to watch. Label and explain the function of the following components shown in the photo below; x- and y- piezo stacks, x- and y-axes flexure levers, x- and y-axes flexure fulcrums, x- and y-axes central stages. Explain what a "nested design" is and what are its advantages compared to the tube piezo.

Photo removed due to copyright restrictions.

Figure 1. 3-axis nanopositioner in Asylum Research, Inc. Molecular Force Probe.

2. **Force-Distance Curves**. A high resolution force spectroscopy experiment was conducted normal to a mica surface (z-direction) using an atomic force microscope with a Si_3N_4 cantilever (k = 0.38 N/m) and probe tip in air. The sample was first lowered to ≈ 1000 nm below the probe tip, data acquisition was initiated, and then the piezo incrementally moved the sample towards the tip in the z-direction relative to the fixed probe tip position, i.e. "approach." Upon contact with the surface, the piezo then reversed direction and incrementally moved away from the tip in the z-direction, i.e. "retract." The raw datafile has been posted on the MIT Server and consists of z-piezo deflection, z (nm) (column 1) versus sensor output, s (V).

a. Convert this data into force, F (nN), versus tip-sample separation distance, D (nm), and plot (feel free to use any software program you would like, e.g. it can be done in an Excel spreadsheet).
b. Explain the origin of the adhesion force given its magnitude and range, as well as the known surface chemistry of mica.
c. Can you calculate an accurate value of the adhesion energy as was done in the 1st assignment, why or why not?
d. Looking at the data, can you tell if the mica is being indented by the probe tip? How?

3. **AFM Imaging : Artifacts.**
An artifact called "tip broadening" sometimes occurs in AFM images whereby the width of a feature appears larger than the true size. As you will see, this phenomenon can actually be used to measure the probe tip radius. Consider the case of a sharp probe tip of triangular geometry imaging a larger nanoparticle fixed to a planar substrate where the tip radius is much less than the feature curvature radius (*Figure 2*).
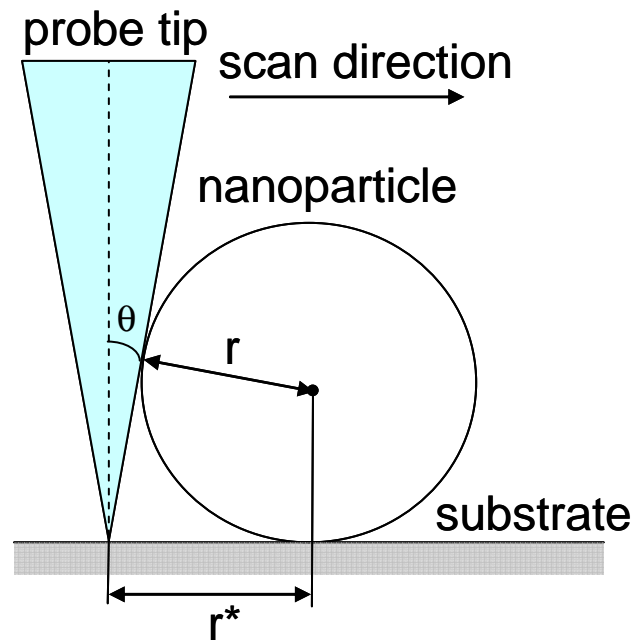
Figure 2. Geometry of a sharp probe tip imaging a spherical nanoparticle where r= nanoparticle radius, r* = defined geometrically in the figure above, θ = probe tip angle.

a. When the nanoparticle is imaged, it does not appear spherical in shape. Draw schematically the 2-dimensional height profile of what the nanoparticle will look like and explain why.
b. Calculate r* in terms of r and θ and then estimate the broadening correction coefficient K where r*=Kr. Plot r*/r versus θ.
c. A tapping mode AFM image is posted on the MIT Server for this problem of 5 nm gold nanoparticles imaged on atomically flat mica. Download the following software which can open this file (http://www.nanotec.es/wsxm_download.html) WSxM v4.0 Develop 10.1. Open the file and based on the image appearance select the height image. Select "Process" from the top drop down menu and then "Profile." Draw a line over a nanoparticle and a height profile plot will appear in another box. Include the image (with the line showing which nanoparticle was used for the calculation) and the height profile in your assignment solutions. Use this data to estimate the probe tip radius.

d. Another imaging artifact may occur whereby the height is underestimated; explain one possible reason for this and the conditions under which it would be likely to occur.

e. A number of papers have reported sub-nanometer scale resolution using relatively large probe tips (50-100 nm radius). Explain how this could be possible.

4. **Podcast 1**: Higgins, M.J. *et al.* "Structured water layers adjacent to biological membranes." *Biophysical Journal* 91, 2532-2542 (**2006**).

a. In this paper, the samples were prepared by the "solution spreading technique." In the podcast, Dr Higgens mentioned that since the paper was published he now has switched to using the "vesicle fusion technique." Research what this technique is and write up a paragraph summary. Define all terms used and cite references appropriately.

b. Dr. Higgins stated that the sample imaged by AFM in Figure 2C was an ideal sample for force measurements. Why is that?

c. Estimate the height of a bilayer based on the chemical structure of the lipids and known bond angles. Then, use this information in conjunction with Figure 6A to explain how Dr. Higgins could conclude that the force oscillations he observed were due to movement through layers of water molecules and not through the lipid bilayer.

d. Dr. Higgens presented another piece of evidence for the hypothesis mentioned in Question 4c, which was that the tip-normalized punch-through force for a lipid bilayer was much higher than the possible range of normalized forces at which he observed force oscillations to occur. Do this calculation and include an explanation of all of numerical values used.

e. What did you find the most interesting part of the podcast/paper?

5. **Podcast 2**: Suresh, S. *et al.* "Connections between single-cell biomechanics and human disease states: Gastrointestinal cancer and malaria." *Acta Biomaterialia* 1, 15-30 (**2005**).

a. Why did Suresh and Mills use a microplate stretcher for their cancer cell experiments instead of the optical tweezer apparatus used to stretch red blood cells infected by malaria parasites?

b. In Figure 6, why does the appearance of the bead attached to the left side of the cell appear different in the 68 pN and 151 pN frames? What effect does this have on measurement of diameter changes? Calculate the actual axial diameter change of the cell in terms of the axial diameter change observed under the microscope. (No numerical values are necessary; use symbolic quantities and define your variables).

c. Rank the following in order of increasing elastic modulus: a healthy red blood cell, a red blood cell infected by the *Plasmodium falciparum* parasite, and a red blood cell infected by the *Plasmodium vivax* parasite. How do the different elastic moduli of these red blood cells affect their ability to remain in circulation throughout the body? Which disease leads to more fatalities? How might fatality be related to these disease-induced mechanical changes?

d. What did you find the most interesting part of the podcast/paper?

Extra Credit : +5 points each for posting a comment on either of the two message boards.