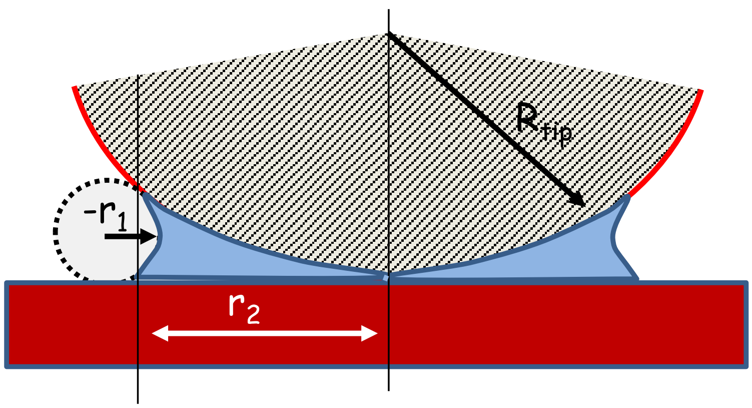
# Homework No. 3

## Fundamentals of AFM: Part I

## Lectures: P1_Wk3_L1 - P1_Wk3_L6

**Problem 1:** A tip of radius $R_{tip}$= 30 nm comes into contact with a flat plane as shown below. The relative humidity of the ambient air is 40%, so a water meniscus forms as shown schematically in the figure. Assume the temperature is 300 K.




**Q1.1.** What determines the radii of curvature $r_1$ and $r_2$?

a) The ideal gas law
b) The Young-Laplace equation
c) The Kelvin equation
d) The First law of thermodynamics

**Q1.2.** If a parameter called the Kelvin radius ($r_K$) is defined as

$$\frac{1}{r_K} = \frac{1}{r_1} + \frac{1}{r_2},$$

what is $r_K$ for the situation described above?

a) -1.76 nm
b) -0.57 nm
c) 0.3 nm
d) 1.4 nm

**Q1.3**. What equation determines the pressure difference across the liquid-vapor interface that forms between the tip and substrate?

a) the ideal gas law
b) the Young-Laplace equation
c) the Kelvin equation
d) the First law of thermodynamics

**Q1.4.** The magnitude of the pressure drop across the liquid-vapor interface is

a) 2.37 GPa
b) 1.06 GPa
c) 0.36 GPa
d) 0.13 GPa

**Problem 2:** Use the default values in VEDA (see table below) to simulate the interaction force of a 10 nm radius tip as a function of tip-sample gap. Select the Hertz contact model.

| | |
|---|---|
| $R_{tip}$ | 10 nm |
| $E_{tip}$ | 130 GPa |
| $\square_{tip}$ | 0.3 |
| $E_{sample}$ | 1 GPa |
| $\square_{sample}$ | 0.3 |

What force is required to indent the sample by 0.5 nm?

a) 0.09 nN
b) 0.4 nN
c) 0.9 nN
d) 1.6 nN

**Problem 3.** Whenever a dynamical system follows the rule that an applied force causes a displacement □z from equilibrium which varies linearly with the applied force, we can write that the system can be described by the equation

$$F_{applied} = k\,\Delta z$$

where k is called the spring constant of the system.

Calculate the spring constant for a Si microcantilever that is $300\text{x}10^{-6}$ m long, $50\text{x}10^{-6}$ m wide and $1.2\text{x}10^{-6}$ m thick.

a) 2.8 N/m
b) 1.3 N/m
c) 0.83 N/m
d) 0.14 N/m

**Problem 4.** The vibration criteria VC-E states that floor vibrations should have a velocity less than 3 □m/s for all frequencies less than 100 Hz.

**Q4.1.** Assume that floor vibrations are primarily caused by different pieces of equipment scattered around the building that have moving parts that undergo cyclic motion when energized. This equipment might reasonably cause the floor to oscillate sinusoidally at some frequency f (in Hz) with a constant amplitude $z_o$. If this is the case, what expression might be used to approximate the floor's vibration as a function of time?

a) $z(t)= z_o (t-t_o)/f$
b) $z(t)= z_o(t-t_o)^2 f$
c) $z(t)=z_o \sin(2\pi ft)$
d) $z(t)= z_o(t-t_o)^2 \sin(2\pi ft)$

**Q4.2.** If a floor meets the VC-E specification, what is the corresponding amplitude of the floor vibration at 50 Hz?

a) 0.6 nm
b) 1.4 nm
c) 3.8 nm
d) 9.6 nm

**Problem 5.** Use VEDA to simulate the interaction force of a 10 nm radius tip as a function of tip-sample gap. Select the DMT contact model. Enter the values given in the table below. Under the tip-sample interaction tab, select the DMT calculation option: *"Enter Hamaker constant and intermolecular distance; autocalculate adhesion force".* This will allow you to input the Hamaker constant explicitly. The questions below can be answered by analyzing the simulation that is graphed when the "tip-sample interaction force vs. gap" is selected in the "Result:" tab.

| | |
|---|---|
| $R_{tip}$ | 10 nm |
| $E_{tip}$ | 130 GPa |
| $□_{tip}$ | 0.3 |
| $E_{sample}$ | 100 GPa |
| $□_{sample}$ | 0.3 |
| $a_o$ | 0.2 nm |

| | |
|---|---|
| H | $1x10^{-19}$ J |

**Q5.1.** What is the interaction force when the tip-sample gap is 1 nm?

a) 0.6 nN, repulsive
b) 0.17 nN, attractive
c) 3.8 nN, attractive
d) 4.2 nN, attractive

**Q5.2.** What is the largest attractive interaction force?

a) 0.6 nN
b) 0.17 nN
c) 3.8 nN
d) 4.2 nN

**Q5.3.** What is the indentation when the applied force is 5 nN?

a) 0.07 nm
b) 0.13 nm
c) 0.36 nm
d) 0.42 nm

**Q5.4.** The indentation determined in Q5.3 is

a) mostly due to the tip being crushed when it comes into contact with the substrate
b) mostly due to a deformation of the substrate when the tip comes into contact with it
c) split roughly equally between the tip being crushed and the sample being indented
d) can't tell from the information provided

**Q5.5.** Before contact, how does the interaction force depend on the tip-sample gap d?

a) $F \propto d$
b) $F \propto d^{-1}$
c) $F \propto d^{2}$
d) $F \propto d^{-2}$