AE 523 – Nanoscale Contact Mechanics
Fall 2023

Instructor: Ioannis Chasiotis (e-mail: chasioti@illinois.edu)
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Class times: Tuesdays and Thursdays 15:00-16:45 (with a 15 min break)
Class location: 125 English Building
Lab Location: Materials Research Lab: B12 MRL and 0013 Supercon
Credit: 4 graduate hours

Meeting Schedule: Two 90-minute lectures per week in weeks 1-11 & 15-16, and two 120-minute laboratory sessions per week, in weeks 12-13. Labs will take place in groups of four students.

Reading and other Materials:

1. J. Israelachvili, *Intermolecular and Surface Forces*, 3rd edition, Elsevier, 2011. Available in Digital Form through the Grainger Engineering Library.
2. K.L Johnson, *Contact Mechanics*, Chapter 4, pp. 84-106, Cambridge University Press, 2003.
3. I.N. Sneddon, *International Journal of Engineering Science* 3**,** 47–57, 1965.
4. W.C. Oliver, G.M. Pharr, *Journal of Materials Research* **7** (6), pp. 1564-1583, 1992.
5. I. Chasiotis, Atomic Force Microscopy in Solid Mechanics, *Handbook for Experimental Solid Mechanics*, Chapter 17, editor: W.N. Sharpe, Jr., Springer, pp. 409-443, 2008.
6. Course notes summarizing the documents above, provided by the instructor (300+ slides).

COURSE OUTLINE:

1. SHORT AND LONG RANGE ATOMIC INTERACTIONS

- **1.1. Short range forces:** Admissible potentials for atomic force interactions, short range electrostatic interactions.
- **1.2. Long range forces:** Electronic and dipole interactions between atoms/molecules, origins of attractive/repulsive van der Waals forces and their retarded forms, electrostatic, capillary, double layer, steric forces, Lennard Jones potential.
- **1.3. Molecular and particle force interactions:** Derjaguin approximation, “bottom-up” derivation of adhesive forces.

2. MECHANICS OF CONTACT AND ADHESION

- **2.1. Herzian contact:** Problem formulation, solution.
- **2.2. Sneddon contact:** Boussinesq problem, solution for singular, non-singular and indeterminate contact profiles.

2.3. Nanoindentation: Problem formulation, derivation of equations for common singular contact profiles from Sneddon's solutions

2.4. Adhesive models based on continuum formulations: JKR, DMT, Maugis/Dugdale, fracture mechanics equivalence, analogies between DMT/Bradley and JKR/Lennard Jones models.

2.5. Capillary forces: Effect of thermodynamic parameters on capillary properties.

3. APPLICATION OF CONTACT MECHANICS TO PROBE MICROSCOPY

3.1. Scanning probe microscopes: Instrumentation, spatial and force calibration, scanner artifacts, tip imaging deconvolution of objects of revolution, thermal noise, energy dissipation at the AFM tip.

3.2. AFM imaging in non-contact mode: Dynamics of AFM cantilevers in free space and under the influence of surface forces, atomic resolution by non-contact AFM.

3.3. Force spectroscopy: Analysis of force displacement curves for van der Waals, repulsive, electrostatic, double-layer, mechanical deformation, (capillary) adhesion, unbinding of receptor–ligand forces, jump-to-contact instability, force resolution.

4. LABORATORY ASSIGNMENTS

4.1. AFM controls: Calibration of AFM cantilever dynamics for high fidelity imaging, PID controls and tip shape determination.

4.2. AFM feature deconvolution: Tip-surface deconvolution, tip calibration and corrected measurements of nanofibers and nanoparticles.

4.3. Force-displacement curves: Measurement of force interactions on hydrophilic and hydrophobic surfaces.

4.4. Nanoindentation Lab: Independent determination of tip area function, calibration of tip area function for pile-up, application of nanoindentation to particle nanocomposites.

Evaluation:

Homework Assignments (4)	20%
Laboratory Assignments (4)	40%
Midterm Exam (written)	20%
Final Exam (oral)	20%