NS 218 Fundamentals of Nanoscience – Spring 2023-2024

Intended Audience: A sophomore level hands-on course for MAT, ME and BIO majors, PHYS minors, or anyone interested in understanding phenomena governing the behavior of structures in the 1-100 nm size range.

Aims: The course is aimed at providing a physics-based understanding of the processes important for nanoengineering. Using simplistic models (in two-dimensions wherever possible) students will develop the heuristics on how man-made nanostructures and biological nanomachines behave. The course will let the students develop the insight for junior-senior level courses where both extensive measurements on materials and biological systems on all scales are made, and the formation of higher order structure is discussed.

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Hours: Mon 11:40–12:30 and Tue 12:40–14:30 (both @ G029)

Office hours: by e-mail appointment; Mon.-Thur. until 20.00

Resources:

(Textbook) Molecular Driving Forces (2nd edition), K. A. Dill and S. Bromberg, Garland Science.
(Reference) Intermolecular and Surface Forces (2nd edition), J. Israelachvili, Academic Press.
++ Some fundamental manuscripts from the scientific literature.

Course Organization: in class lectures with hands-on sessions and structured instruction.

Evaluation will be based on two midterms (25 % each), final (40 %), class & other participation (10 %).

COURSE OUTLINE:

Week 1 (Feb. 19, 20): Basic problems, limitations, opportunities at the nanoscale: Time and length scales in structures; energy landscapes; fundamental forces that operate at the atomistic scale; interplay between force and energy; reporting errors in measurements.

Week 2 (Feb. 26, 27): The problem of stickiness of small things & how to work around it: Interactions between atoms, between particles, etc.

Week 3 (Mar. 4, 5): Interactions continued; Hamaker constants, etc.

Week 4 (Mar. 11,12): How long does it take to travel around in a nanoscale structure? Diffusion at the nanoscale. Brownian ratched as an example of converting binding & release events into directed motion.

Week 5 (Mar. 18, 19): Putting together time and length scales at the nano-World. Why are the cells the size they are, and other back-of-the envelope calculations at the nanoscale.

Week 6 (Mar. 25, 26): Review for Midterm I and **Midterm I (Mar. 26; in class)**

Weeks 7 (Apr. 1, 2): Adsorption, binding and catalysis at the nanoscale.

Spring Break

Weeks 8 (Apr. 15, 16): Why do salts ionize in water? Effect of ionic strength and charges on properties of nanostructures.

Weeks 9-10 (Apr. 22,29,30): Why are systems always neutral? Born model of ion solvation. Charge distribution in solution near nanoparticles with uniform surface charges

Week 11-12 (May 6-7; 13-14): Self-assembly; the simple example of hydrophobic self-assembly

Week 13 (May 20, 21): Review for Midterm II and **Midterm II (May 21; in class)**

Week 14 (May 27, 28): Measurements at the nanoscale with the aid of forces: AFM, FRET, pulling experiments.

LEARNING OUTCOMES:

At the end of the course, the learner is expected to develop a working knowledge of the physical phenomena operating at the nanoscale (1-100 nm size range).

Upon completion of **NS218 Fundamentals of Nanoscience**, the students should be able to:

1. list the differences between the properties of nano- and macroscale materials.
2. calculate basic intermolecular interactions between atoms and/or particles and classify them as strong/weak based on a comparison with thermal energy.
3. categorize forces as short- versus long-range based on the power dependence on separation.
4. relate time scale of motion of nanoparticles to their sizes using the diffusion equation.
5. identify nanomachines and classify them, e.g. as transporter, catalyst, motor, etc.
6. calculate the charge distribution near nanoparticles with uniform surface charges.
7. describe the effect of salt on the behavior of nanoparticles.
8. given the general interaction parameters of a mixture of molecules, identify if a self-assembly process will be observed and estimate the morphology of the final equilibrium structure.
9. explain hydrogen bonding and the driving forces that lead to hydrophobic behavior.
10. evaluate results obtained from experiments based-on forces operating at the nanoscale.