Physics 053:
Handcrafting in the Nanoworld:
Building Models and Manipulating Molecules

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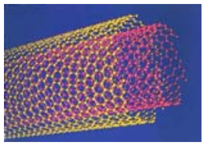
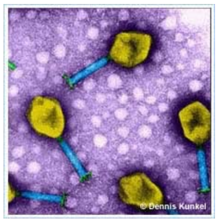
What is Nanoscience? What is Nanotechnology?

Scientists of all stripes are now actively exploring the wonderful and bizarre world of the nanoscale (one nanometer equals one billionth of a meter). This is the scale of molecules, DNA, viruses and a host of other fascinating nano-objects that you might not have heard of (carbon nanotubes, quantum dots, molecular motors …). At this scale, nature has different rules, some of which are beautiful and unexpected. Scientists have only begun to learn these rules. In this course, we will study the unusual objects and properties of the nanoworld through class discussion, hands-on activities that include model building (with model kits, Lego etc.), nano-calculation homework sets, and actual nanoscale experiments. This hands-on approach is intended to instill a sense of science as an ongoing creative process, where an individual's original, creative thought plays a central role. Our goal is to gain an appreciation of the science of the nanoscale as well as its technological implications.

Small is different



The content of this class will consist of three themes: **A.** a review of some of the more important nano-objects; **B.** the unique properties of the nanoscale; and **C.** a review of experimental techniques that allow scientists to interact and analyze these objects. Of course, these themes will be integrated. We will build physical models of nano-objects around which we will discuss their structure, properties and the experimental techniques used to study them.



A. The Nanoscale Zoo (nano-objects)

Our discussions will be centered on particular nano-objects such as carbon nanotubes, viruses, DNA etc. We will build models of these objects to become familiar with their constituent parts as well as their overall structure and scale. We will concentrate on systems that are most relevant to today's research in physics, materials science and biology.

B. Properties of the Nanoscale: "Small is Different"

Objects made up of hundreds or thousands of atoms have properties that differ significantly from larger objects that we are familiar with in our daily lives. We will explore the science of what makes "small different" in terms of properties, forces and energy. We will concentrate on three key distinguishing characteristics of the nanoscale: **bumpiness** (things tend to be *bumpy* rather than *smooth*), **stickiness** (everything sticks together; gravity is irrelevant!), and **shakiness** (everything shivers and shakes; nothing stands still).

C. Scientific Techniques

Our ability to interact with and evaluate the nanoworld has come in large part from advances in microscopy. We will review the various new kinds of microscopes being used today and discuss how they work. We will also take a look at how computers are used to visualize the nanoscale as well as simulate the properties of nano-objects.

Daily Activities

A. Model Building

You will construct models from molecular model kits, arts and crafts materials, Lego or whatever is needed to represent the nano-objects that we are studying. In addition, magnets, Velcro and the like will be used to represent forces between objects. The purpose of this exercise is to create a tactile experience with the geometry and constituent parts of the nano-objects, as well as the forces between or within them. Getting an intuitive sense of the *absolute* as well as the *relative* scale of objects (DNA relative to a Virus), and the *range* of forces is extremely important for thinking creatively about this strange world. Model building will also serve as a jumping off point for class discussions about the properties and structure of the nanoscale. ***These projects will require preparation before project day which will usually include answering a few questions. After the projects are completed, a short write up will be made of the project and turned into me. Detailed description of the model projects and the write ups are give on the course web page***.

B. Reading Assignments/Discussion

Reading assignments will be made every week to two weeks. You are required to read the material and have designated questions answered by the due date. We will use these questions as an outline for class discussion. Your responsibility for this activity is to come to class ready to discuss the subject. Have comments and questions ready for me and your class mates. I will expect proactive engagement in these discussions. These discussions will be where we really hash out the different concepts of nanoscience and nanotechnology. You should use these sessions to clarify things you don't understand about the readings or express your opinions or enthusiasms about things that you've read.

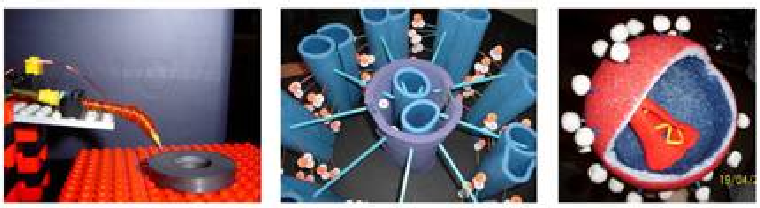
Projects

A. Final Model Building Project.

Midway through the semester, we will form teams and begin discussing a final building project for each team. These projects will be more involved and require more research, building and original design ideas than the day to day model projects. Projects should require some significant research which will mean library research and/or proper web research. I will give each team a lot of guidance on these projects. Initially we will simply be meeting to discuss the projects and forming plans for our models. Toward the end of the semester, we will devote class time to model building; though some of your work will probably have to be done outside of class. These final projects will be presented to the rest of the class along with a write-up

Possible Final Building Projects . . .

- ***Model of a Molecular Motor that moves***
- ***Self Assembling model using Lego and Magnets that mimics the assembly of a protein or virus***
- ***Model of a Carbon nanotube or Molecular Circuit***
- ***Model of a Magnetically actuated Nanoswitch***
- ***Detailed Model of a Cilium or Flagellum that shows the nanometer scale motors and microtubules structure.***



Examples of final projects. Left: a LEGO magnetic force microscope model. Middle: a model of a cross section of a cilium. Right: a model of an HIV virus.

B. Execute a Nanoscience Experiment

Several experimental sessions will be scheduled on the nanoManipulator. The nanoManipulator is a virtual reality interface for microscope experiments in which nano-objects can be pushed, stretched and squashed (for real!!). Depending on class size, either sub-groups or the class as a whole will accompany the instructor to perform these experiments. This activity will take place in two or three sittings of 2 to 3 hours each. The results of these experiments will be written up.

Tests

There will be one midterm exam as well as a final exam. These exams will be in short answer or essay form, and may include some calculations. Within each exam you will be required to describe particular nano-objects that were built and discussed in class. These descriptions will include a discussion of the structure and properties of the nano-object (which will include drawings). Also, excerpts from articles in the popular press on nanoscience will be included for critical analysis in short essay form.