Syllabus

Introductory remarks: What are nanostructures and why should you care?

A nanostructure is reasonably defined as an object possessing at least one critical dimension less than 100 nm in extent. By that defintition nanostructured systems are all around us all the time, an are already prevalent in technology. Certainly molecules fit the bill, and chemists have effectively been performing nanoscience for many years, albeit with large numbers of nanostructures . Within the last 20 years, however, a new set of tools have been developed that allow precise engineering of materials on scales approaching that of single atoms. Simultaneously, progress has created an ever-increasing demand for further miniaturization of existing technology, to the point that the physical principles on which that technology is based are at the edge of their validity.

This is a consequence of a simple yet profound observation: the properties of matter on the nanometer scale can be vastly different than those on the macroscopic scale. The borders between physics, chemistry, and materials science become blurred, and lessons may be learned from molecular biology, the nanoscience of living things.

When matter is confined or structured on the nanometer scale, some physics that matters little in bulk systems may dominate important properties like electrical conduction, mechanical strength, or equilibrium structure. The newly relevant physics may have its origins in classical effects: *e.g.* the classical charging energy of a capacitor may exceed room temperature thermal energy if the capacitor is made small enough. Alternately, new phenomena may arise statistically from the reduction in N, the number of atoms, from a thermodynamically large value (10^{22}) to a small value (100): *e.g.* as the surface to volume ratio for a metal cluster becomes very large, the thermodynamically stable cluster crystal structure can change dramatically. Finally, quantum mechanical effects (*e.g.* tunneling, quantum interference), typically relevant at very short length scales, may become dominant when system sizes approach the nm regime.

Understanding the physics of matter structured at the nm scale is one of the most active areas of research today. The reasons are clear: access to this new size scale is of fundamental scientific interest, and the technological importance of the knowledge gained is potentially astronomical. In many ways this is reminiscent of solid state physics research in around 1950. Scientists are making gains in understanding the fundamental properties of these new systems; simultaneously they are making laboratory demonstrations of possible technological spin-offs; industrial adoption of these systems is just getting off the ground; and forecasting the long-term industrial impact fifty years down the line is essentially impossible. It's a fairly safe bet, however, that the physics of nanostructures will have a massive impact on all of us - as we'll see in this course, it already has.

The style of the course

This course is a continuation of PHYS533. As such, I will **not** spend the first several weeks of the course on a review of solid state physics, as you did last semester. Rather, we will focus our efforts on three main topics. For each topic, I will provide some background information about the relevant physics. Then we will examine the state-of-the-art in the topic, discussing the importance of nanoscale phenomena. We will then consider future directions in the topic, with an emphasis on relevant physics at the nanometer scale.

Structure and grading

The course will consist of three one-hour lectures per week. There will be (roughly) weekly problem sets, given out on **Wednesday** and due the following **Wednesday** at the beginning of class. Late work will only be accepted if due to illness or emergency - I want a legitimate excuse.

Understanding the material is at least as important as getting a numerically or formulaically correct answer to the problem. If your reasoning isn't obvious, please write little explanations of what you're doing and why, so partial credit can be assigned in a reasonable way.

Unsurprisingly, it's rather difficult to come up with lots of homework problems that are really relevant, produce physical insight when solved, and are tractable in a reasonable time frame. You will find that most of the problems I assign are not terribly calculationally intense, and often involve some kind of verbal interpretation of what's going on. Learning to communicate your physical understanding through writing is an important and often neglected skill, so please put some effort into it.

I encourage you to discuss the problem sets with each other. You may give each other guidance and advice on problem solving approaches, and you may compare solutions to check your work. However, you may not copy solutions from another student, you may **not** dig around for previous years' solutions, and the problem sets you submit must be entirely your own work and your own words. If you use a book, journal article, or website, you must cite the relevant material. If you collaborated strongly with other students, cite them as well - this is intellectual honesty.

I'm going to do the lectures in PowerPoint format, and to make them available over the Web afterward. There will be additional notes and handouts available from the website as well - please check here if you miss class. Furthermore, there will be a few guest lectures during the semester.

For now, I'm planning on the following grading scheme:

50% homework
20% first paper
25% second paper
5% participation

The papers will be pledged. A list of possible topics will be released later in the semester, along with details of what I want. These papers **must** be your own work - **you must cite all sources used, and if you quote someone else's material, you must clearly indicate that**. Treat this like a real-world document you'd be sending to referees, or like a technical memo you'd be sending to your boss. There are two papers because I think it's better to give you a chance to get some feedback on your writing rather than have it be a "fire and forget" process. At the beginning of the course, **I will make you sign a document indicating that you understand this**. I know this sounds childish and legalistic, but experience has taught me that it is, unfortunately, a good idea.

"Participation" is tough to quantify, but I'd like to try this to encourage you to ask questions, particularly about the reading assignments. Trust me - if there's something in the course you find unclear, you're unlikely to be alone. Talking about these topics with each other and with me is a better way to learn the material than trying to do it in a vacuum.

Honor Code issues

All work on exams and problem sets is subject to the Honor Code. I take the Honor Code seriously, and I expect you to do the same. The homework and final paper situations have been described above. If you have any questions about this, raise them with me at the beginning of the course.

Here is the "Grading and Honor Code policy" statement that all students in this course are required to read, sign, and return to me.

Course Outline

This is a brief outline of topics to be covered in the course. A detailed breakdown will be available on owlspace and updated as the semester progresses. We may have to shift gears and rearrange topics, but I hope to get through all this.

I. Overview and introduction

II. Physical optics

Reflection and refraction; Frauenhoffer diffraction; DBR mirrors; lasers

III. Photonics

Optical fibers; semiconductor lasers; nonlinear optical effects; solitons; optical switching; single photon devices

IV. Continuum mechanics

Stress and strain; elasticity; mechanical properties of solids; damped nonideal harmonic oscillator

V. Micro- and nano-electromechanical systems (MEMS and NEMS)

Fabrication; mechanical properties of MEMS and NEMS; accelerometers; motors; gyroscopes

Thermal properties of NEMS; quantum effects; Casimir force; mass detection + charge manipulation; tribology

VI. Fluid mechanics

Dimensional analysis: an example of what physicists can learn from engineers

Inviscid fluids: a primer

Viscous fluids: a primer

VII. Micro/nanofluidics + advanced sensors

Life at low Reynolds number

Capillary forces; electrophoresis+electroosmosis;