Course Outline
Math 824 - Special Topics: Mathematical Directions in Micro- and Nanoscale Science
Spring 2005

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Last year the U.S. Government invested over $960 million in nanoscience research. Worldwide, government investment in nanoscience is approaching $3 billion per year. To put these numbers in perspective, note that $960 million represents about 17.5% of the budget of the National Science Foundation and that the U.S. investment in nanotechnology has doubled in only three years. Why are we investing so much in nanoscience and nanotechnology? What can we expect the field to return? Over what period of time and at what cost? Why does a Google search on "nanoscience" return 400,000 hits? What are all of these nanoscience researchers doing? Answering these questions will be the focus of this course. Through critical reading of the primary literature in micro- and nanoscale science you'll build an understanding of the rapidly developing fields of micro- and nanoscale science. We'll discuss these readings and try and understand what the implications of nanoscience are for mathematics, for science, and for society.

If you choose to take this course you will need to:

- *Read regularly and critically* - Selected readings from the scientific literature will form the entire basis for this course. You'll need to read them on time and learn to ask questions of what you are reading. You'll develop your skills in reading as a mathematician reads. You'll evaluate and discuss the arguments set forth in these selected papers. You'll learn to start with a key article, trace its impact on the field, and fill in gaps in your knowledge as you go.
- *Present and Participate* - Class discussions will guide our inquiries, everyone in the class has something to contribute and shouldn't hesitate to contribute it! In addition, everyone in the class will take

primary responsibility for 1-2 articles. They will lecture on these articles and lecture on any background information needed to understand these articles. They will steer the discussion and class inquiry in a direction informed by their reading.

- *Attend Class* - If you choose to take this class, you'll need to attend. Every class meeting will involve discussion and examination of articles you will have read. It is impossible to get the full benefit of reading these articles without testing your understanding against that of your classmates. Don't decide to take this class without committing yourself to attending each and every class.

Assessment: Your grade in this class will be based on how well you answer the questions we decide to ask. Are you willing to spend $5 billion on the strength of your answer? Will you change your research direction? Should I? Evidence of your understanding will include class participation and oral presentations.

Class Readings: The articles we will read, a brief description of each, and our course timetable are listed below. The course web page contains a link to a zip file of all articles except those noted below.

2/9, 2/14 - The start of it all

For the first two classes we will discuss the transcripts of two talks by Richard P. Feynman:

"There's Plenty of Room at the Bottom," Richard P. Feynman, reprinted in Journal of Micromechanical Systems, Vol. 1, pp. 60-66, 1992.

"Infinitesimal Machinery," Richard P. Feynman, reprinted in Journal of Micromechanical Systems, Vol. 2, pp. 4-14, 1993.

We'll also discuss the more recent overview of nanotechnology:

"Plenty of Room Indeed," Michael Roukes, Scientific American, pp. 48-57, September 2001.

2/16 - Is small different?

We'll spend one class thinking about scaling laws and discussing the classic paper by Trimmer.
"Microrobots and Micromechanical Systems*," W.S. Trimmer, Sensors and Actuators, Vol. 19, pp. 267-287, 1989.

2/21, 2/23 - The first MEMS device

The first real MEMS device was built at Westinghouse in the late 60's. It used the principle of electrostatic actuation - a principle still central to micro- and nanoscience. We'll read and discuss the article by Nathanson.

"The Resonant Gate Transistor*," H.C. Nathanson, et. al., IEEE Transactions on Electron Devices, pp. 117-133, 1967.

2/28, 3/2 - Carbon Nanotubes

Starting this week I'll stop talking and all further lectures will be given by students in the class. One of the key items driving nanoscience is the carbon nanotube. This week we will look at electrostatic deflections of nanotubes.

"Electrostatic Deflections and Electromechanical Resonances of Carbon Nanotubes," P. Poncharal, et. al., Science, Vol. 283, pp. 1513-1516, 1999.

"Nanomechanics of Individual Carbon Nanotubes from Pyrolytically Grown Arrays," R. Gao, et. al., Physical Review Letters, Vol. 85, pp. 622-625, 2000.

3/7, 3/9 - Carbon Nanotubes II

The nanotube is amazingly versatile.

"Elastic Response of Carbon Nanotube Bundles to Visible Light," Y. Zhang and S. Iijima, Physical Review Letters, Vol. 82, pp. 3472-3475, 1999.

"Conductance Quantization in Multiwalled Carbon Nanotubes," P. Poncharal et. al., Eur. Phys. J., Vol. 9, pp. 77-79, 1999.

3/14, 3/16 - Putting things together

One of the more vexing problems in nanoscience is finding efficient ways to build nanoscale structures. One answer is *self assembly*.

"Self-Assembly of Mesoscale Objects into Ordered Two-Dimensional Arrays," N. Bowden, et. al., Science, Vol. 276, pp. 233-235, 1997.

"Forming Electrical Networks in Three Dimensions by Self-Assembly," D. Gracias, et. al., Science, Vol. 289, pp. 1170-1172, 2000.

3/21, 3/23 - DNA Computing

The entire field of DNA computing was launched by the three page paper by Adleman.

"Molecular Computation of Solutions to Combinatorial Problems," L.M. Adleman, Science, Vol. 266, pp. 1021-1023, 1994.

4/4, 4/6 - DNA Tinkertoys

DNA self-assembles! (Note J. Chen is a faculty member at UD, we can invite him to speak to the class if you wish.)

"Design and self-assembly of two-dimensional DNA crystals," E. Winfree, et. al., Nature, Vol. 394, pp. 539-544, 1998.

"Synthesis from DNA of a molecule with the connectivity of a cube*," J. Chen and N. Seeman, Nature, Vol. 350, pp. 631-633, 1991.

4/11, 4/13 - Self Replication?

In addition to building nanoscale objects through self-assembly, nanoscientists would like nanoscale objects to build copies of themselves. This is the idea behind *self-replication*. The first paper is old, less than one page long, but absolutely beautiful.

"A Self-Reproducing Analogue*," L.S. Penrose and R. Penrose, Nature, No. 4571, p. 1183, 1957.

"Self-Reproduction in Cellular Automata*," C. G. Langton, Physica D, Vol. 10, pp. 135-144, 1984.

TBA*

4/18, 4/20 - Nanomedicine

This week we turn to two recent articles that point the way toward medical applications of nanotechnology. In the second article, the atomic force microscope (AFM) is discussed. This is one of the great enabling technologies of nanoscience.

“Electrical Detection of Single Viruses,” F. Patolsky, et. al., PNAS, Vol. 101, pp. 14017-14022, 2004.

“Single-Walled Carbon Nanotube AFM Probes: Optical Imagine Resolution of Nanoclusters and Biomolecules in Ambient and Fluid Environments,” L. Chen, et. al., Nano Letters, Vol. 4, pp. 1725-1731, 2004.

4/25, 4/27 - Molecular Motors

So, you can build small objects, or even have them build themselves, but how do you make them move? We’ve already seen how to use electrostatics for this purpose; another approach is to build very small motors. The idea of a *Brownian Ratchet* is essential here.

“Thermodynamics and Kinetics of a Brownian Motor,” R. D. Astumian, Science, Vol. 276, pp. 917-922, 1997.

“A Reversible Synthetic Rotary Molecular Motor,” J. Hernandez, et. al., Science, Vol. 306, pp. 1532-1537, 2004.

5/2, 5/4 - Micro- and Nanofluids

As in the macro-world, fluids play an essential role in micro and nanoscale systems. The review article by Ho and Tai is quite lengthy, the presenter might want to focus on a few of the fundamental issues raised.

“Micro-Electro-Mechanical Systems (MEMS) and Fluid Flows,” C. Ho and Y. Tai, Ann. Rev. Fluid. Mech., Vol. 30, pp. 579-612, 1998.

“Formation, Stability, and Breakup of Nanojets,” M. Moseler and U. Landman, Science, Vol. 289, pp. 1165-1169, 2000.

5/9, 5/11 - Slack Week

I expect we will run at least a week behind schedule. I’m leaving some slack in the schedule!

5/16, 5/18 - Ethical Issues?

At this point in the semester we’ll all have a good idea of what nanoscience is all about, what is feasible, and what is not. We’ll wrap up with a discussion of the ethical implication of nanoscale research. Our focus will be on the cautionary article by Bill Joy:

“Why the future doesn’t need us,” Bill Joy, Wired, April 2000.

We’ll also read the more positive article by Phoenix and Drexler:

“Safe exponential manufacturing,” C. Phoenix and E. Drexler, Nanotechnology, Vol. 15, pp. 869-872, 2004.

*Starred articles are *not* available in the zip file on the web page. They will be handed out in class.