Math 824 – Mathematical Directions in Micro- and Nanoscale Science

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MEC Lab — Modeling Experiment Computation — Department of Mathematical Sciences — University of Delaware

Assignments

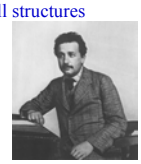
1. Carbon Nanotubes
   - Ying Liu
   - ?
   - (Regan Beckham)
2. Carbon Nanotubes II
   - Albert Yawson
   - ?
   - (Stephan Mensah)
3. Putting things together
   - Christine Phelps
   - ?
4. DNA Computing
   - Pam Kosick
   - ?
   - (Todd Gutekunst)
5. DNA Tinkertoys
   - Christine Picarro
   - ?
   - (Junghuei Chen)
6. Self Replication?
   - Tom Fleetman
   - ?
7. Nanomedicine
   - Derick Moulton
   - Jen Tonkin
8. Molecular Motors
   - Kristel Orben
   - Michael L. Vaughan
9. Micro- and Nanofluids
   - Paula Vasquez
   - Ana Vasilic
   - (Anand Vyas, Soumitra Deshmuk, Pam Cook)

Feynman 1959

1. Can we write small and build very small structures and machines?
2. How do we write small? Build small?
3. What should we build with?
4. What are the ultimate limits?
5. What can we learn from nature?
6. How will the physics differ from the macroworld?
7. Why would we want to build small?

Feynman 1959

1. Can we write small and build very small structures and machines?



"The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom."

"Atoms cannot be perceived by the senses. They can never be seen or touched, and exist only in our imagination. They are things of thought."

Feynman 1959

1. Can we write small and build very small structures and machines?

The kT Irony

$$\frac{m}{2} < v >^2 = \frac{3}{2} kT$$

Feynman 1959

2. How do we write small? Build small?

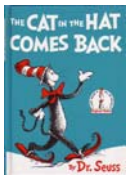
"…reverse the lenses of an electron microscope…"

"…evaporate the material…"

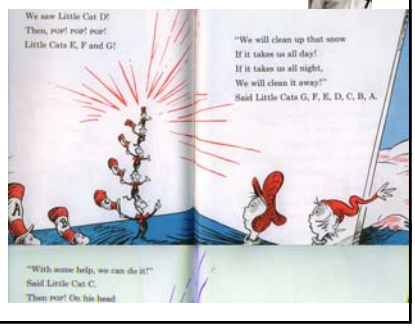
"Why can't we drill holes, cut things…"

"…a master-slave system…"

Feynman 1959



Or Seuss 1958?



Feynman 1959

3. What should we build with?

Doesn't seem to consider the question seriously from the point of view of microsystems, but ultimately answers that we can build atom by atom and "synthesize any chemical substance that the chemist writes down."

Feynman 1959

4. What are the ultimate limits?

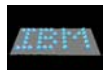
"The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom."

Feynman 1959

5. What can we learn from nature?

"Biology is not simply writing information; it is *doing something* about it. Consider the possibility that we too can make a thing very small, which does what we want – that we can manufacture an object that maneuvers at that level."

Observations about biology later became the key counter-argument in the kT irony debate. The debate was finally settled when the STM was developed and atom by atom manipulation became possible.



D.M. Eigler, E.K. Schweizer. **Positioning single atoms with a scanning tunneling microscope.** *Nature 344, 524-526 (1990).*

Feynman 1959

6. How will the physics differ from the macroworld?

- Scaling issues regarding strength of material
- Grain structure of metals
- Magnetic properties scale funny
- Lubrication problem
- Heat transfer is more rapid
- Rapid heat transfer prohibits combustion
- Van der Waals forces become significant
- The problem of resistance

Scaling

Feynman 1959

7. Why would we want to build small?

Hmm…no idea, maybe really tiny surgeons? Better computers?

Feynman 1983

1. What progress has been made in fabrication techniques?
2. Why would we want to build small?
3. How can we make small machines move?
4. What can we learn from nature?
5. How will the physics differ from the macroworld?
   - Problem of precision
   - Problem of friction and stiction
6. How do we make a small computer?

Feynman 1983

1. What progress has been made in fabrication techniques?

•Lithographic techniques, he calls these "evaporation"

•Sacrificial layers, release method

Feynman 1983

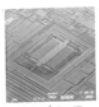
2. Why would we want to build small?

"…no particular use for small machines. You will see that there has been no progress in that respect."

•Accelerometer (air bag sensor)

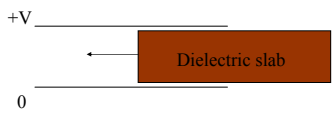
•LCD projectors

•Nanopants

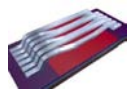


Feynman 1983

3. How can we make small machines move?



"The forces that will move these parts are not big enough to bend anything very much; things are very stiff at this dimensional scale."



Feynman 1983

4. What can we learn from nature?

•Swimming is more difficult

•ATP as an energy source

•Biology has motors!

"One always looks at biology as a kind of a guide…not a perfect guide…"

Feynman 1983

5. How will the physics differ from the macroworld?
   - Problem of precision
   - Problem of friction and stiction

The science of scale – how do effects change in relation to one another as we change system size?

Feynman 1983

6. How do we make a small computer?

Store information using spin states.
(Anticipates spintronics)

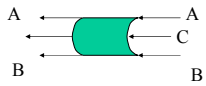
What about operations?

"…atomic physics is reversible."

Feynman 1983

6. How do we make a small computer?

"…irreversibility is not essential for computation."



Roukes 2001

1. Have we reached Feynman's vision? Why not? How do we get there?
2. How does the physics differ from the macroworld?
3. Why would we want to build small?
4. What are the fundamental challenges being addressed today?

Roukes 2001

1. Have we reached Feynman's vision? Why not? How do we get there?

"We've only just begun to take the first steps toward his grand vision of assembling complex machines and circuits atom by atom."

"…there is a fundamental science issue…"

"It is the science of the *mesoscale*…"

Roukes 2001

2. How does the physics differ from the macroworld?

"…there is a fundamental science issue…"

"It is the science of the *mesoscale*…"

"…these systems are not so large as to be completely free of quantum effects…"

Roukes 2001

2. How does the physics differ from the macroworld?

Macroworld

Microworld

Mesoworld

Atomic World

Macroworld = Our length scale

Microworld = MEMS, small, but continuum mechanics ok

Mesoworld = Too many atoms, but still quantum effects

Atomic World = Single Atoms

Roukes 2001

3. Why would we want to build small?

Sensors, in particular resonant sensors!

Roukes 2001

4. What are the fundamental challenges being addressed today?

Challenge I: Communication between the macroworld and the nanoworld.

Challenge II: Surfaces

Some things to talk about

- Can you point out any essential questions that Feynman and Roukes have overlooked? Or that I overlooked in my reading of them?
- As a scientist, engineer, or mathematician, would you frame the Feynman/Roukes questions differently? Would you ask different questions?
- What questions do you find most important? Why? If you wanted to explore nanoscience what questions would you seek answers to first?
- Which of the questions raised by Feynman and Roukes do the papers you'll present seem to address?