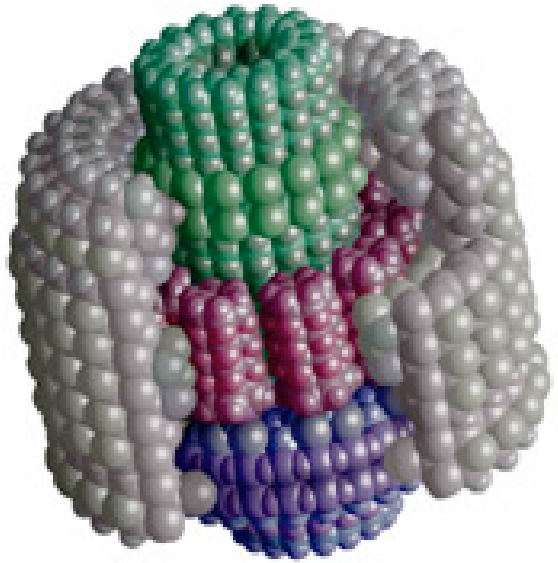
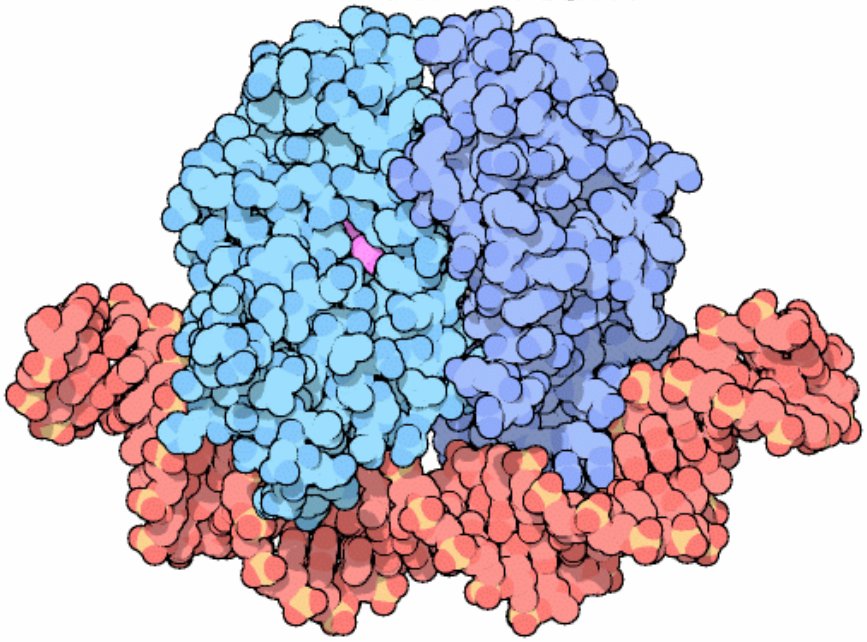
COMPSCI 296.05 (Spring 06)

- Background Nanotechnology, What is BioNanoTech?
- Biomaterials
  - Biomacromolecules (DNA, RNA, protein) (structure & engineering)
  - Other biomaterials (lipids, carbohydrates, inorganics)
- Methods and Instruments
  - Molecular biology, synthetic chemistry
  - Microscopy (AFM, TEM, SEM, STM, etc.)
- NanoMaterials
  - nanoparticles, nanotubes, nanowires, nanocrystals, block co-polymers
- Nucleic Acid Nanotech
  - DNA-based computing, algorithmic self-assembly. RNA nanotech.
- Protein Nanotech
- Molecular Robotics. Molecular Diagnostics. Molecular Electronics.
- BioNano with Protein, Virus, Cell Building Blocks.
- Impacts: biosensors, molecular theraputics, nanoelectronic, nanooptical, nanochemical, molecular manufacturing.

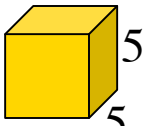
Nano and BioNano

- Nanotech--atomic control of matter
- Bionanotech--control of matter on low nanometer scale with inspiration, principles, or materials borrowed from biology.





Feynman, 1959



5 atoms = 125 atoms

- **There's Plenty of Room at the Bottom**
  - **Encyclopaedia Brittanica on the head of a pin requires only 25,000 fold reduction.**
    - **1/25,000 pixel = 80 Å (8 nm) = ~32 metal atoms in 2D or 1000 atoms in 3D**
  - **Read- press metal stamp into soft plastic mold, evaporate silica onto plastic to make a thin film, shadow at low angle with gold to highlight raised letters, then examine using electron microscope.**
  - **Write- focused ion beam (TV cathode ray spot), suggests photo process with light shining through holes in a screen could effect metal atoms on surface or some other chemical which could be patterned and recognized later (lithography).**
  - **All books in the world would fit on 1 million pin heads (about 3 square yards). Can we encode to improve information density?**
  - **Atomic info: 2D surface, 3D atomic crystal. If a bit could be encoded in a cube 5x5x5 atoms then "all books in world" would require 10^{15} bits and would fit in a cube 1/200 inch wide.**
  - **Biological information density (~50 atoms per bit).**
  - **Need better EM**

Feynman, 1959

- **There's Plenty of Room at the Bottom**

- **Physical arrangement of atoms -> chemistry**
- **Miniaturize computers (heat, power, speed)**
- **Miniaturize machines (smaller->smaller->smaller)**
  - **Parallelism**
- **Molecular electronics**
- **Mechanical tolerance**

Only TOP-DOWN view [no self-assembly]

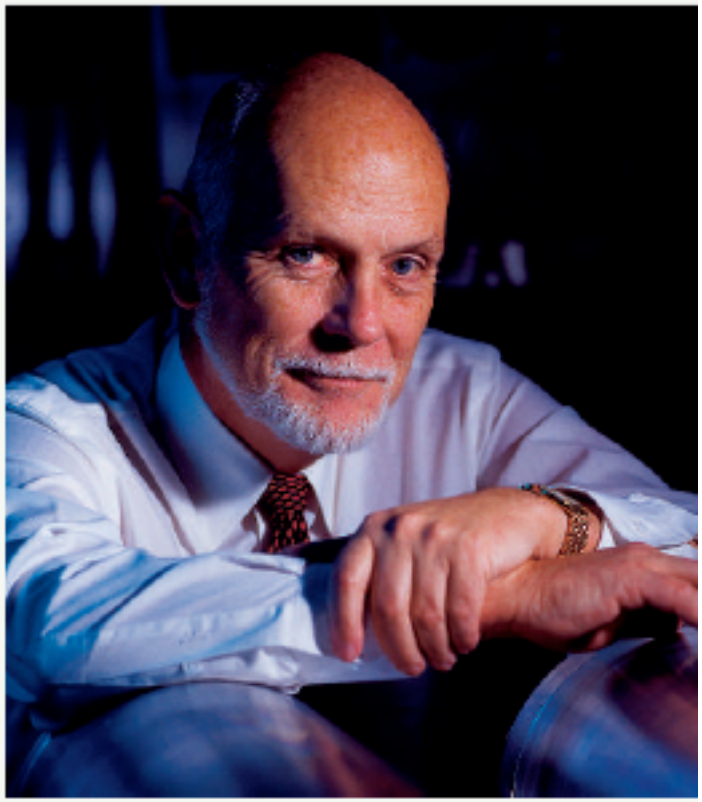
NEWS & VIEWS

OBITUARY

Richard E. Smalley (1943–2005)

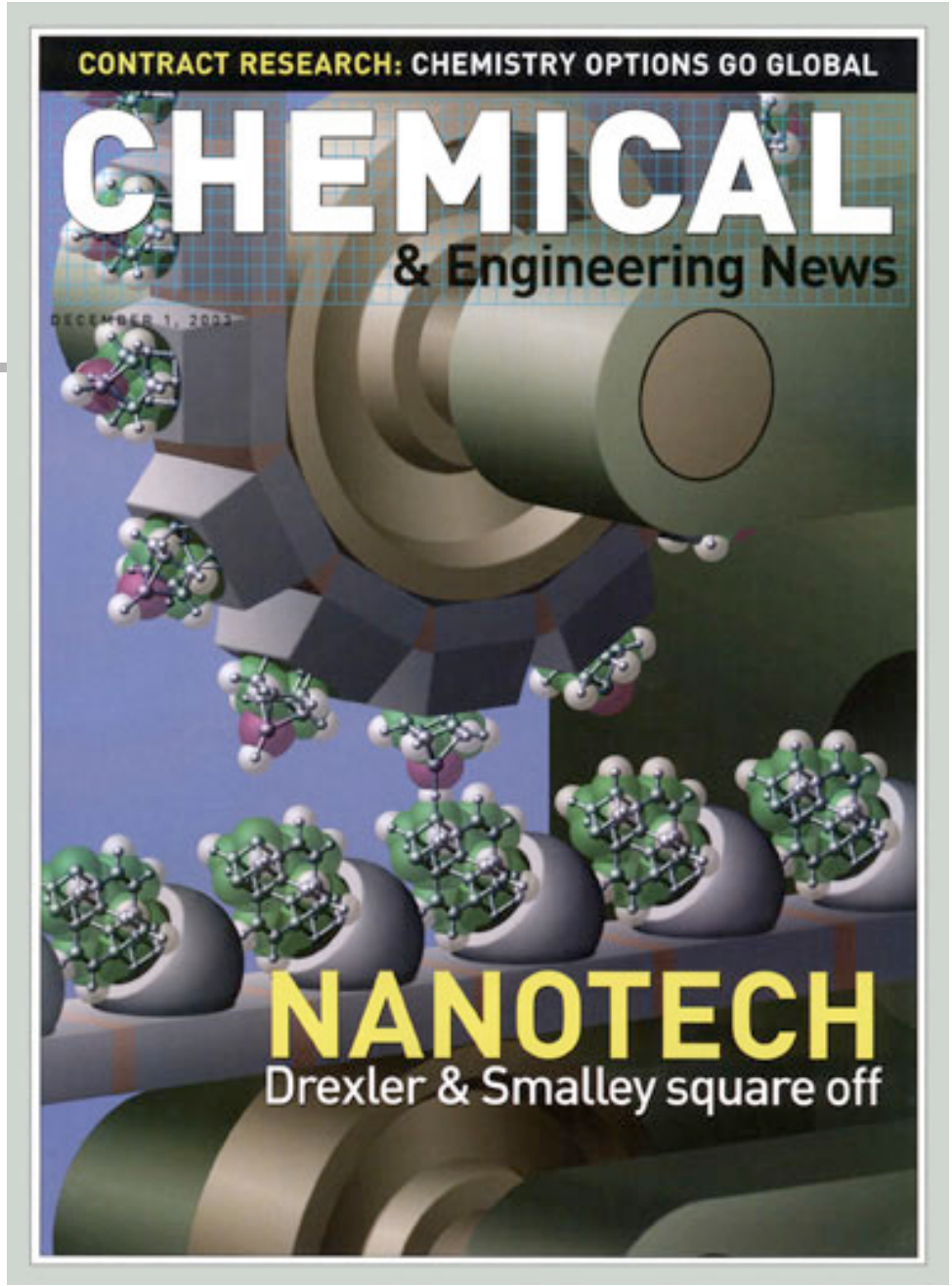
Chemist and champion of nanotechnology.

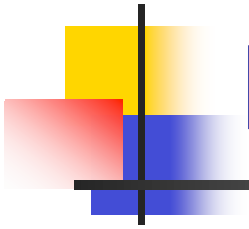
NATURE | Vol 438 | 22/29 December 2005



Drexler vs Smalley

- Drexler
  - Molecular assemblers will provide atom-by-atom manufacturing
- Smalley
  - “fat fingers problem”
  - “sticky fingers problem”

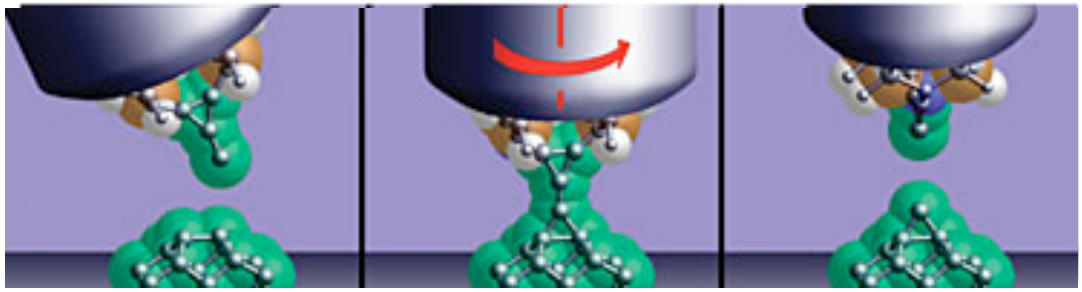




Drexler, 1981

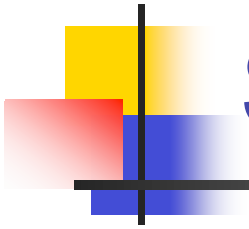
- Drexler (1981) PNAS
  - Microtechnology
  - Protein design and engineering
  - Protein enzymes = molecular robots
  - Prediction: protein-based assemblers will be the tools needed to advance molecular manufacturing
- Bottom-up approach
- http://www.foresight.org
- What is your opinion?
  - “Visionary proponent of a new technology”
  - “Hype-man for the-next-big-flop”

Drexler



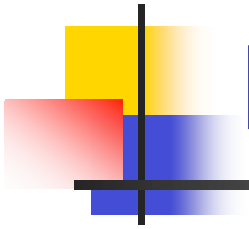
MECHANOSYNTHETIC REACTIONS As conceived by Drexler, to deposit carbon, a device moves a vinylidenecarbene along a barrier-free path to insert into the strained alkene, twists 90° to break a pi bond, and then pulls to cleave the remaining sigma bond. COURTESY OF K. ERIC DREXLER

- Molecular assemblers will perform molecular manufacturing.
- Atom-by-atom control via mechanical positioning of reactive molecules (not by manipulating individual atoms). “Smalley fingers” are not required.
- No by-products. No pollution.
- “Replicating assemblers and thinking machines pose basic threats to people and life on earth.” Gray goo hypothesis.
- Potential for abuse of advanced nanotechnologies means peaceful countries should invest and stay ahead.



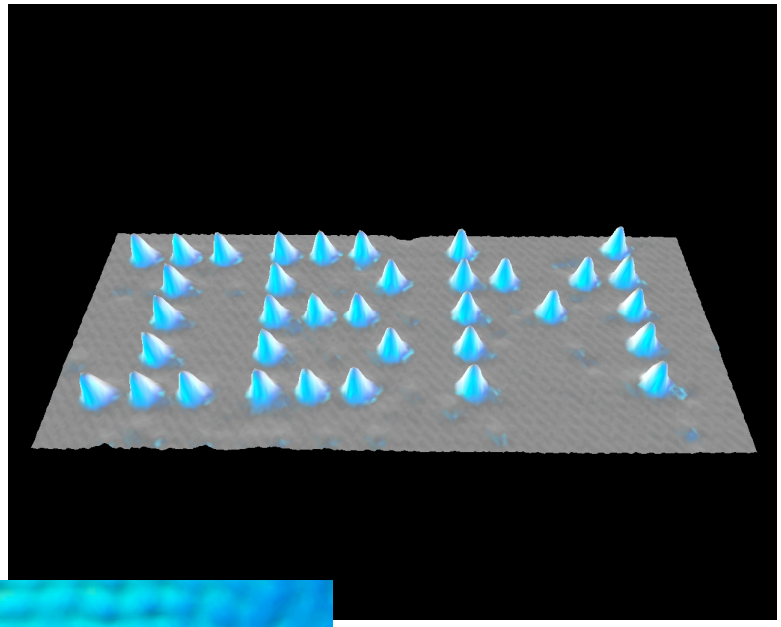
Smalley

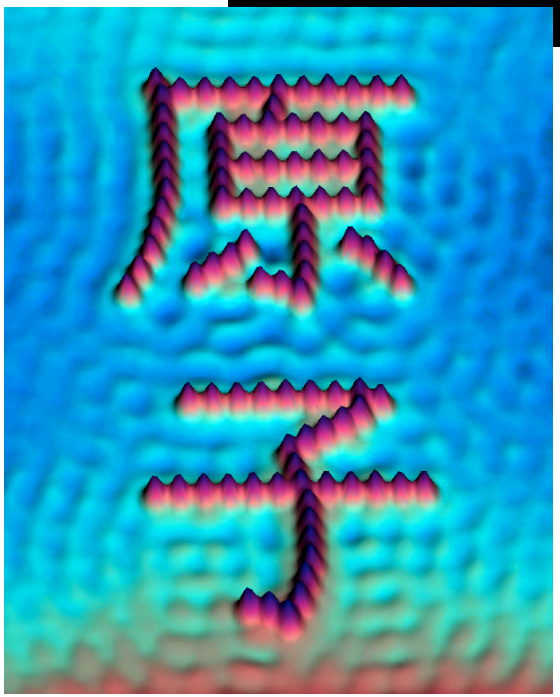
- Molecular assemblers are not physically possible.
- Talks about the impossibility of computer controlled assemblers. Enzymes required.
- Talks about the need for water. States that enzymes can not work in organic solvent.
- Speculation about unrealistic potential dangers of nanotechnology threaten public support for it.



Drexler

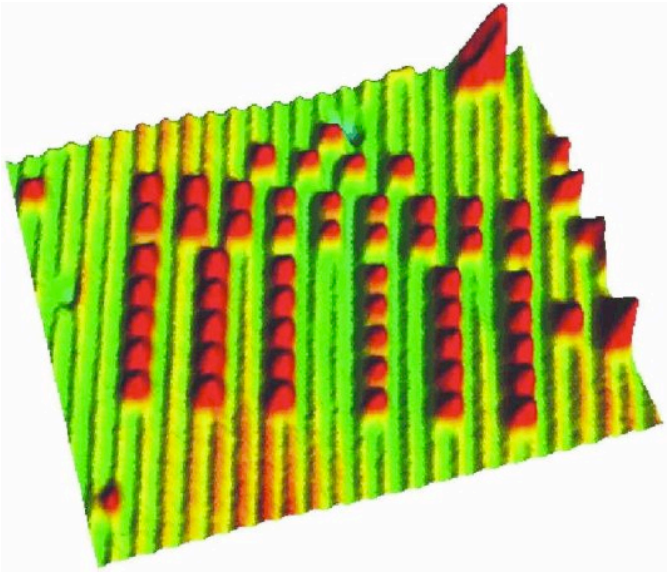
- Quoting Smalley: “when a scientist says something is possible, they’re probably underestimating how long it will take. But if they say it’s impossible, they’re probably wrong.”
- Some simple “machine phase” chemistry using STM manipulation of atoms has already been achieved.





Single-atom manipulation

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



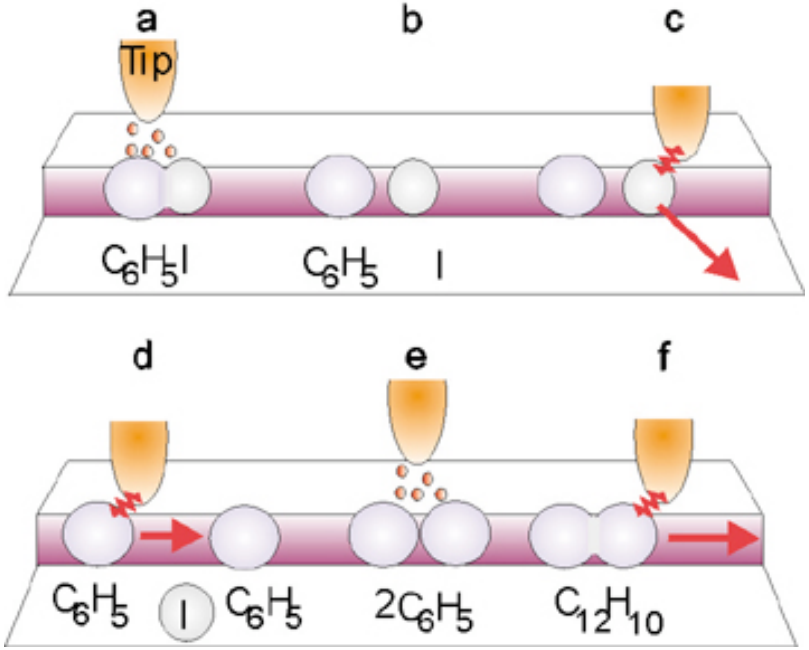
See also:
http://www.europhysicsnews.com/full/21/article4/article4.html

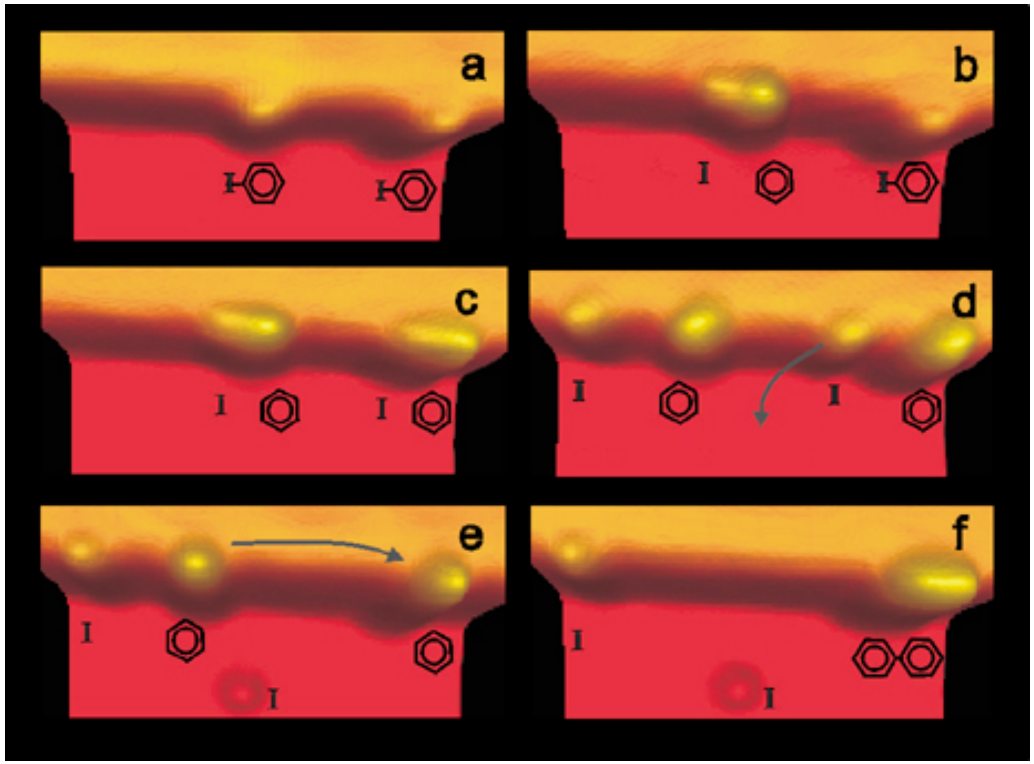
VOLUME 85, NUMBER 13 PHYSICAL REVIEW LETTERS 25 SEPTEMBER 2000

Inducing All Steps of a Chemical Reaction with the Scanning Tunneling Microscope Tip: Towards Single Molecule Engineering

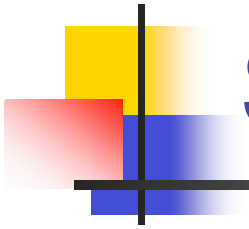
Saw-Wai Hla,[1,2,*] Ludwig Bartels,[1,†] Gerhard Meyer,[1] and Karl-Heinz Rieder[1]

Chemistry by STM



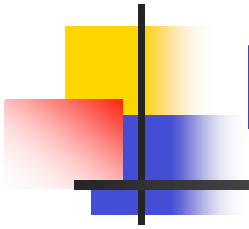


Schematic drawing of the sequence of steps by which an STM probe can
(a) dissociate a C6H5I molecule on a terrace;
(b and c) draw iodine atom away;
(d) pull one C6H5 (phenyl) molecule toward another;
(e) weld them together; (f) pull one phenyl to confirm the association



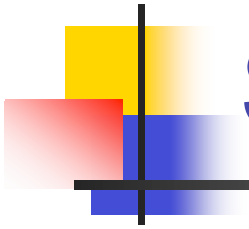
Smalley

- Exaggerates about enzymes' need for water.
- Not entirely correct about biological systems not utilizing metals.
- "If [there can be] a non-water-based life form, then there is a vast area of chemistry that has eluded us for centuries." (His own work demonstrates that there are vast areas of chemistry that have eluded us for centuries!)



Drexler

- Makes leap of faith from something like “biology has already done it” to something like “everything is possible and controllable”
- Overly optimistic timeframes?
- Schematics show atoms at points of chemistry but mysteriously smooth materials elsewhere. Of course, on that scale it’s atomically bumpy everywhere. Problems?



Smalley

- If nanobots use enzymes and water then they cannot perform chemistry with materials that are unstable in water.
- They will be restricted to biologic-like materials: rock, wood, flesh, bone.
- They could not make Si crystals, steel, aluminum, titanium or other “key materials on which modern technology is built”…

Magnetosomes in Bacteria

U. Heyen & D. Schler Growth and magnetosome formation by microaerophilic Magnetospirillum strains in an oxygen-controlled fermentor Appl Microbiol Biotechnol (2003) 61:536–544

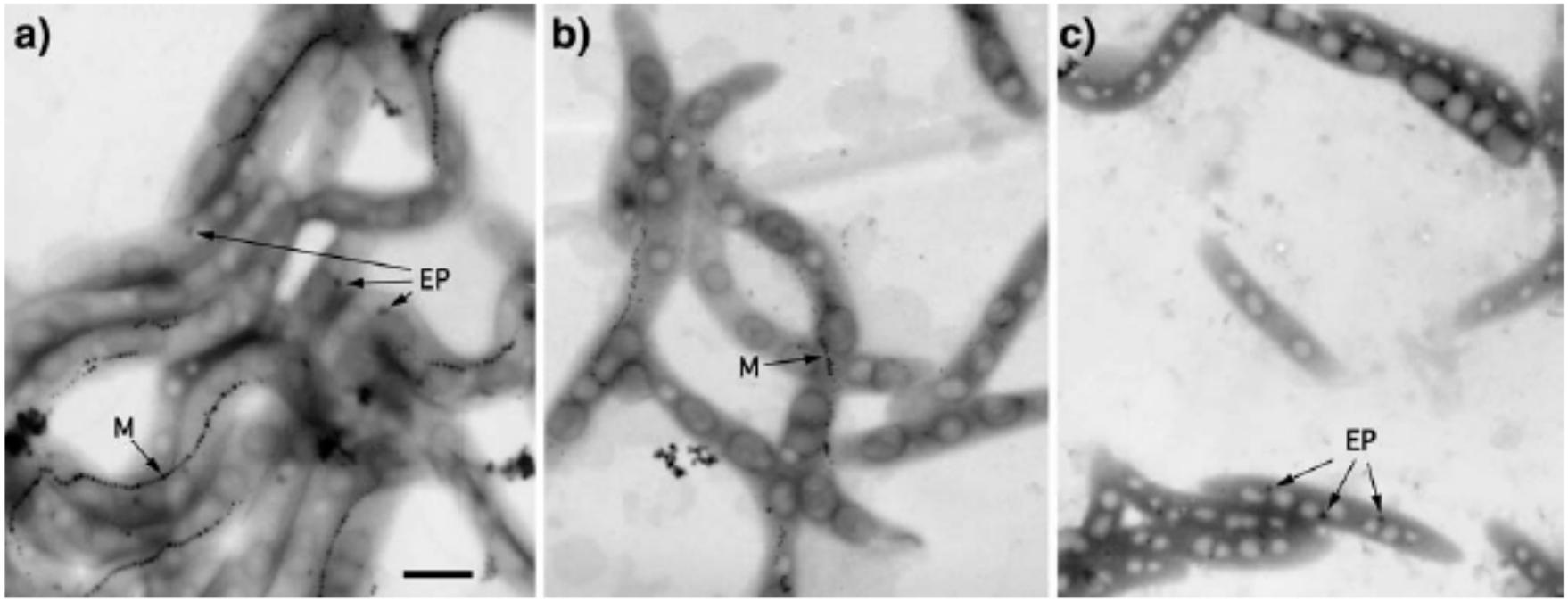
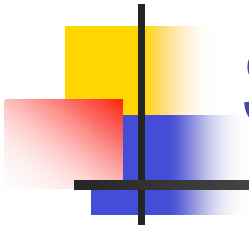


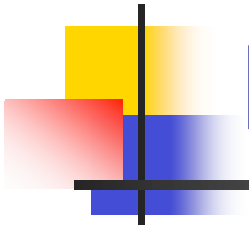
Fig. 3a–c Electron micrographs of *M. gryphiswaldense* cultures grown in the oxystat at defined pO_2 tensions of 0.25 mbar (a), 10 mbar (b), and 20 mbar (c). *Arrows* indicate the magnetosome chains (*M*) and the electron-dense particles (*EP*) found in magnetic and non-magnetic cells. The bright inclusions represent polyhydroxyalkanoate globules. *Bar* 0.5 µm

Magnetite = Fe_3O_2



Smalley

- Nearly half of essays from high school and middle school students assumed that self-replicating nanobots were possible and most were worried about what would happen when they spread around the world.
- “You and people around you have scared our children.”

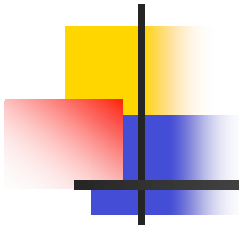


ETC group - What's to fear?

- Below ~50 nm quantum size-effect means quantum mechanics takes over from classical mechanics.
- Unpredictable properties - macro-gold is yellow, nano-gold is red.
- Powerful chemistry - Catalyst material made of particles 10 nanometers in diameter is about 100 times more reactive than the same amount of the same material made of particles one micrometer in diameter.
- "Green Goo"

Tech Review Process

ETC Evaluation



Laws of Technology Introduction

1 It takes a full human generation to comprehend the ramifications of a new technology. Therefore, decisions about whether or not or how to use a new technology will necessarily be ambiguous. Society must be guided by the Precautionary Principle.

2 In evaluating a new technology, the first questions must be: Who owns it? Who controls it? By whom has it been designed and for whose benefit? Who has a role in deciding its introduction (or not)? Are there alternatives? Is it the best way to achieve a particular goal? In the event of harm, with whom does the burden of liability rest and how can the technology be recalled?

3 The extent to which a new technology may be beneficial to society will be in proportion to the participation of society in evaluating the technology—including and especially those people who are most vulnerable.

4 A new technology cannot definitively be assessed as "positive," "negative" or "neutral," although certain technologies—in an equitable environment—may be intrinsically decentralizing, democratizing and helpful.

5 For every so-called "Luddite" attempting to establish social controls over the introduction of a technology, there is a powerful elite using social controls to impose new technologies on society.

6 The introduction of a new technology is not inevitable.

7 Any new technology introduced into a society that is not itself a just society can exacerbate the gap between rich and poor—and may even directly harm the poor.

8 A new technology cannot be a "silver bullet" for resolving an old injustice. Hunger, poverty, social disablement and environmental degradation are the consequences of inequitable systems—not of inadequate technologies.

9 The leaders of a society who permit injustice are the least likely to introduce a new technology that will correct injustice.