Nanotechnology

- Nanofabrication techniques
- Characterization techniques
- Single electron transistors
- Quantization of electrical resistance
- Nanotubes, nanowires

Units

- Meter (m)
- Millimeter (mm) = 10^{-3} m
- Micrometer (μm) = 10^{-6} m
- Nanometer (nm) = 10^{-9} m
- Picometer (pm) = 10^{-12} m
- Femtometer (fm) = 10^{-15} m

Length scales

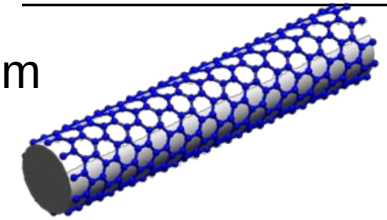
Nanotube

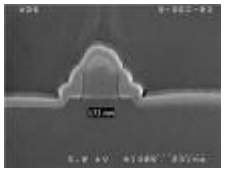
Smallest lithographic resolution

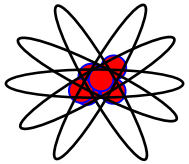
Si transistor

1970 Si transistor (10 μm)

Atom





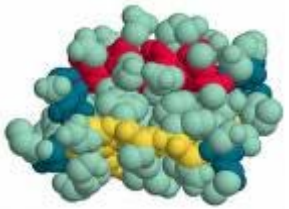


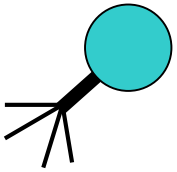
DNA

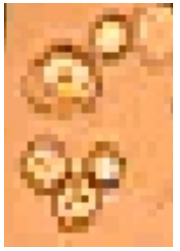
Protein

Virus

Cell







1 A | 1 nm | 10 nm | 100 nm | 1 μm | 10 μm

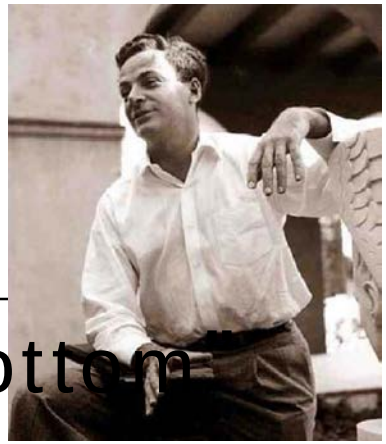
What is nanotechnology?

- "Top down" approach
  - Micron scale lithography
    - optical, ultra-violet
    - Focused Ion Beam
  - 10-100 nm
    - Electron-beam lithography
- "Bottom up" approach
  - Chemical self-assembly
    - Man-made synthesis (e.g. carbon nanotubes)
    - Biological synthesis (DNA, proteins)
  - Manipulation of individual atoms
    - Atomic Force Microscopy
    - Scanning Tunneling microscopy

A brief history of nanotechnology

- Democritus in ancient Greece: concept of atom
- Rutherford, 1900: discovery of atomic nucleus
- Feynman, 1960: speech at Caltech
- Drexler, 1986, 1992: *Engines of Creation*, *Nanosystems*
- Clinton, speech, Caltech, 2000
- *National Nanotechnology Initiative* since 2000

Feynman challenges



- "There's Plenty of Room at the Bottom"
- Feynman, Caltech 1960 set two challenges
  - Construct a 1/64 cubic inch motor
  - claimed in 1960
  - On display at Caltech today
- Encyclopedia Britanica on head of a pin
  - Actualy on page in 10 microns^2
  - Claimed in 1985
  - Used electron-beam lithography

Foresight challenges

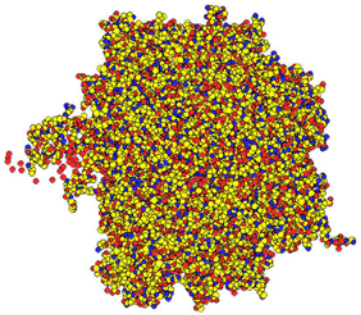
- Drexler wrote two books:
  - 1986: *Engines of Creation: The Coming Era of Nanotechnology*
  - 1992: *Nanosystems: Molecular Machinary, Manufacturing, and Computation*
- Foresight/Feynman $250,000 prize
  - 100 nm arm nano-robot
  - 50 nm^3 8-bit adder

Biosystems

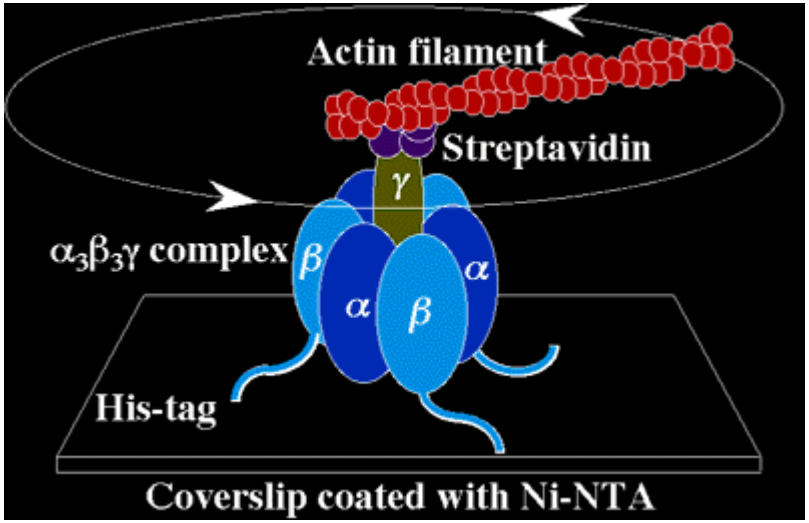
- DNA
  - 2-3 nm per base pair
  - Human genome contains ~ 10^9 base pairs
- Proteins
  - typically 1-10 nm in size
  - ~ 100,000 different proteins in human genetic code
  - all are synthesized enzymatically (bottom up)
- Biological Nano-motors
  - ATP synthase
  - Kinesin, Actin important for muscle movement
- *Nanotechnology is important for life itself*

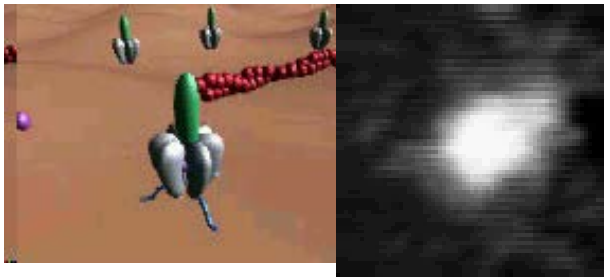
ATP Synthase

- 10 nm nanomachine at the mitochondria membrane
- Uses proton gradient to convert ADP to ATP
- Extremely important for metabolism



10 nm





Movie source: www.res.titech.ac.jp

References: Boyer, Annu. Rev. Biochem. 1997
Yoshida, Nature Rev. Mol. Cell Bio. 1997
Soong, Montemagno, Nature, 2000

Nano-manufacturing

- Lithography can do 10 nm
- Tricks to 2 nm
- Biosystems can add 2 carbon atoms at a time
  - typical in lipid biosynthesis
  - enzymes are nano machines
- We do not know how to design enzymes, only copy them
- As such, nanotechnology does not yet exist according to Drexler's definition

Readings this lecture covers

- Ferry, pp. 1-5
- Feynman, "*There's plenty of room at the bottom*"
- Moore's law original paper
- Moore's law slides
- Drexler ch. 2
- Hanson p. 1-14

Course themes

- *Nano-electronics:* Wave/particle duality
- Particle:
  - Charging energy e^2/C (single electron transistor)
- Wave:
  - Gradually reduced dimensions:
    - 3 (bulk)
    - 2 (2DEG)
    - 1 (nanowire)
    - 0 (quantum dot).
  - Quantization of electrical resistance: e^2/h