What is nanotechnology?

What is nano?

Why is it important?

How do we make nano?

How do we characterize nano?

What are physical and chemical properties of “nano”?

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
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<td>Radium</td>
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</table>

Total = 6.71x10^27

Adapted from R. Freitas, Nanomedicine Vol I (1999)
How Small is Nano?

- One nanometer (nm) is one billionth, or $10^{-9}$ of a meter
- One human hair (cross section) is about 100,000 nanometers.
- Larger than Nanoscale is the microscale, and smaller than that is the atomic scale.

How Small is Nano?

What is Nano?

<table>
<thead>
<tr>
<th>Abbreviations and Size</th>
<th>Description</th>
<th>Unit</th>
<th>Conversion</th>
<th>Scale</th>
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<td>cm</td>
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<td>millimeter</td>
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<td>micrometer</td>
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<tr>
<td>nanometer</td>
<td>nm</td>
<td>1/100000000</td>
<td>1X10^-9</td>
<td></td>
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<tr>
<td>angstrom</td>
<td>Å</td>
<td>1/19000000000</td>
<td>1X10^-10</td>
<td></td>
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</tbody>
</table>
M.C. Roco (National Science Foundation), 2001.
“One nanometer is a magical point on the dimensional scale. Nanostructures are at the confluence of the smallest of the human-made devices and the largest molecules of living things. Nanoscale science and engineering here refer to the fundamental understanding and resulting technological advances arising from the exploitation of new physical, chemical and biological properties of systems that are intermediate in size, between isolated atoms and molecules and bulk materials, where the transitional properties between the two limits can be controlled.”

WHAT IS NANOTECHNOLOGY?
The next “Big Thing” Is very very very small!
“Nanotechnology is an enabling technology that will change the nature of almost every human made object in the next century.”
National Science and Technology Council—2000

Nanotechnology is...
Field of science whose theme is the control and manipulation of matter on an atomic and molecular scale to create novel structures, devices and systems.

Nano-sizing Causes Changes in:
- Color
- Crystal shape
- Melting Points
- Conductivity
- Magnetism
- Chemical Reactivity

Uses and Potential Uses of Nanomaterials/Devices
- Sun Screen
- Drug Delivery
- DNA Recognition
- Immunological Labeling
- Book Preservation
- Computers
- Harder Metals
- Information Storage
- Refrigeration
- Solar Cells
- Water Purification
- Better Batteries
- Burn Treatments
- Air Purification
- Solder Ceramics
- Self-Cleaning Windows
- Refrigeration
- Smart Magnetic Fluids
- and Points
- Homeland Security
- Paints
Rayleigh Light Scattering of Nanocrystals: Shape, Size, and Composition Matter

There is Plenty of Room at the Bottom

- The concept of nanotechnology was first coined by Richard Feynman in 1959 in his lecture "There's plenty of room at the bottom"
- Manipulating material at a scale of individual atoms and molecules
- Imagining the whole Encyclopedia Britannica written on head of a pin

The Feynman Vision

I want to build a billion tiny factories, models of each other, which are manufacturing simultaneously.

— Nobel prize-winning physicist Richard Feynman
Nanotechnology

- The term Nanotechnology was first used in 1974 by Norio Taniguchi to refer to a precise and accurate tolerances required for machining and finishing.

- In 1981 K. E. Drexler (now at the Foresight Nanotech Institute for Molecular Manufacturing), talked about molecular manipulation and molecular engineering.

- In 1986, Drexler published a book "Engines of Creation", which finally popularized the term Nanotechnology.

- In 1985 researchers reported the discovery of the "buckyball", a round molecule consisting of 60 carbon atoms.

- This led in turn to the 1991 discovery of a related molecular shape known as the "carbon nanotube".

Carbon Nanotubes

- Carbon nanotubes are molecular-scale tubes of graphitic carbon with outstanding properties.
- Length-to-diameter ratio greater than 1,000,000
- Structurally, carbon nanotubes are 100 times stronger than steel and can conduct electricity better than copper.

The Structure of Nanotechnology
Nanotechnology depends upon...

- Physics
- Chemistry
- Biology
- Computer Science
- Electrical Engineering
- Mechanical Engineering

Nanotechnology is...

- The boundary between atoms and molecules and the macro world
- A great challenge for human being to be able to control materials at atomic scale

Injectable Nanobots?

Approaches

- Bottom-up: Materials and devices are built from molecular components which assemble themselves chemically by principles of molecular recognition.
- Top-down: Nano-objects are constructed from larger entities without atomic-level control.
Nano Robots

Nanorobotics is the technology of creating machines of robots at or close to the microscopic scale of a nanometer.

- Using special bacterium-sized "assembler" devices, nanotechnology would permit on a programmable basis exact control of molecular structures that are not readily manipulated by natural molecular machines and molecular techniques presently available.
- With nanotechnology, atoms will be specifically placed and connected, all at very rapid rates, in a fashion similar to processes found in living organisms.

Cancer treatment

- Cancer cells can be killed without the painful side effect of chemotherapy.
- Scientists may now be able to destroy tumors without killing healthy cells at the same time.
Space benefits of nanotechnology

- Improvement in Shuttles
- Benefits to the Astronauts
- Cheaper space flights
- Nano satellites

Improving Shuttles

- Much lighter in weight and smaller size
- Nano sensors and nano robots
- Micro and nano-rovers for planetary exploitation

Nanotechnology for Astronauts

- Space suits
- Nano food
**Nano food?**

- Preservation of food without refrigeration
- Protection of food from bacteria and diseases
- Lighter foods

**Proposed Ideas**

- Nano Satellites
- Space Elevator

**Nanosatellites**

- Nano satellites will be 90% lighter
- With much greater strength
- Greater safety margin due to the use of Diamondiod fibres that NT can produce

**Carbon Nanotube**

- Stiffest and strongest fibres known, with remarkable electronic properties and unique characteristics.
- They are the result of synthesis of buckminsterfullerene, C60 and other fullerenes.
Space elevator

- Is a proposed structure designed to transport material from celestial body's surface into space.
- A tensile structure would be held in tension between earth and the counterweight in weight, like a guitar string held taut.

Nano in Defence

- Fundamental Changes in the Way Structures and Electronic are Made
- Promise of Lighter Weight and Higher Strength Structures
- Promise of Smaller, Faster Electronics Devices (Molecular Electronics)

DEFENCE

- Promise of New Types of Sensors, Smaller and More Accurate
- Multifunctional Materials
- Improved Weapons
- Conventional and structural materials could be replaced by more rigid and lighter materials
Nanotechnology in Electronics

- Improving displays screens on electronics devices
- Memory chip with a projected density of one terabyte of memory per square inch or greater
- Reducing the size of transistors used in integrated circuits

Computers

- Role in new logic and storage technologies
- Magnetic RAMs and resonant tunnel elements in logical circuits in the near future
- Nanoscale transistors
- Precision, abstraction, and high-throughput production of components that will also be found in molecular manufacturing systems.

Energy

- Nanotechnologyical materials in solar cells and fuel cells.
- Nanotechnological materials which are superconducting at room temperatures to reduce the high transmission losses in our centralized energy supply
- Nanomaterials can be used to improve the capacity of batteries.
- Solar plastics
- Nanoscale powders

Road Ahead

We should close this office... Everything that needs to be invented, is already...

Director, US Patent Office, 1929

I think there is a world market for maybe five computers

Thomas Watson, chairman of IBM 1943

640 k should be enough for everyone!

Bill Gates, 1982
Nanotechnology Education

- The first program involving nanotechnology was offered by the University of Toronto.
- Bachelor of Science in nanotechnology, Master of Science in Nanotechnology, and PhD in Nanotechnology.

Rice University NanoKids

- The NanoKids program is an educational program headed by a Rice University professor. The Web site includes a story with NanoKids as the main characters. It also includes fun activities for teachers to use in teaching nanotechnology.
  www.nanokids.rice.edu

Videos

- "When Things Get Small"
  This is a 27-minute video covering many important nanotechnology concepts in a humorous and entertaining way.
  www.ucsd.tv/getsmall
- "The NANO Revolution"
  Educators may request a free DVD copy of this introductory video about nanotechnology aimed at middle and high school students.
  www.mrssec.virginia.edu

RISKS
Health Risks

- Ultrafine particles can catalyze chemical reactions in the body
- Carbon nanotubes can cause infections of lungs
- They could easily cross the blood-brain barrier, a membrane that protects the brain from harmful chemicals in the bloodstream.

Social and Ethical risks

- More powerful weapons
- Privacy
- What happens to all the manufacturing jobs?

Benefits AND Risks

Lifesaving medical robots AND Untraceable weapons of mass destruction
Networked computers for everyone in the world AND Networked cameras so governments can watch our every move
Rapid invention of wondrous products AND Weapons development fast enough to destabilize any arms race

What is Needed Now

- Awareness of the issues
- Technical research
- Policy research
- New networks
Impact on everyday life

• Nanotechnology was seen to have the second greatest impact, trailing only genetic engineering.

Economic impact of nanotechnology

Market Size Predictions (within six years)
- $340B/yr Materials
- $300B/yr Electronics
- $180B/yr Pharmaceuticals
- $100B/yr Chemical manufacture
- $70B/yr Aerospace
- $20B/yr Tools
- $30B/yr Improved healthcare
- $45B/yr Sustainability

$1 Trillion, growing to $2.6 Trillion by 2014

*Estimates by industry groups, source: NSF and LUX

US Federal funding trends in nanotechnology 2001-2009

Nanotechnology ...

is already making today's products:
- Lighter
- Stronger
- Faster
- Smaller
- More Durable

Aerogel: the world's lightest solid

Aerogel is an ultra-low density solid, a gel in which the liquid component has been replaced with gas. Nicknamed "frozen smoke", aerogel has a content of just 5% solid and 95% air, and is said to be the lightest weight solid in the world.

Despite its lightness, aerogel can support over 2,000 times its own weight. One of the current applications is as insulation for space suits.
Insulation

- Nanoscale materials hold great promise as insulators because of their extremely high surface-to-volume ratio. This gives them the ability to trap still air within a material layer of minimal thickness. Insulating nanomaterials may be sandwiched between rigid panels, applied as thin films, or painted on as coatings.
- Pioneer Builders (of Drumright) now offers Nanoinsulate spray-on insulation with an equivalent r-value of 50.

ARC Outdoors

- ARC Outdoors utilizes nano silver in making cloth for special purposes and currently has a line of anti-microbial clothing for hunters because the nano silver cloth eliminates odor/scent. These clothes are sold through Bass Pro Shops, Cabalas and some Wal-Mart stores.
- ARC is working on developing a line of hospital uniforms that also will be anti-microbial.

Nano Cable

- Nano Ridge Material and Boeing (Long beach) are partners on a $5.75 million Advanced Technology Program to develop Nano Cable by 2010. Nano Cable is a lightweight, highly conductive, electrical wire and cable that could bring significant gains in fuel savings, energy efficiency and operating costs.
- The technology is based on carbon nanotubes which conduct greater amounts of electric current than copper while having only 1/6th the weight.
- By 2010, the market for conductive polymer cable is expected to be 465 million lbs per year, worth $1.4 billion annually.

Nano Coatings

- Self-cleaning
- Scratch-resistant
- Anti-icing and anti-fogging
- Antimicrobial
- UV protection
- Corrosion-resistant
- Waterproofing
In 2002, Eddie Bauer apparel became the first brand to employ Nano-Tex stain resistance technology in its designs. Nano-Tex has now expanded to bring stain resistance to fabrics and other interior finishes. Nano-Tex uses a process that bonds to each fiber, making textiles last longer, retain their natural feel and breathe normally.

### Anti Stain Coatings

- **XetaComp** (Lawton) manufactures nanoparticles of titanium dioxide that enables the production of a "clear", non-greasy, non-oily sunscreen called SunVex.
- Their nanoparticles may soon be in many other skin care products.

### Automotive Paint – Mercedes-Benz

The 2007 Mercedes-Benz SL series cars sport a protective coating of nanoparticles that provides a three-fold improvement in the scratch resistance of the paintwork.

### Martin Bionics/OrthoCare Innovations

Martin Bionics was funded to develop a dry prosthetic device using a super-hydrophobic powder exclusively licensed from Oak Ridge National Labs. They are the only prosthetic company who may have solved this industry problem.
High Quality, High Volume Carbon Nanotubes

Southwest Nano-Technologies is fast becoming the world leader in high quality, high volume, lower cost carbon nanotubes using an patented scalable process that will allow them to produce kilotons rather than kilograms of high quality carbon nanotubes.

Self Healing Composites

Polymeric and composite materials are subject to weakening due to fatigue cracking. A self-healing composite has the potential to defend against material failure due to fatigue and to greatly improve product safety and reliability.

Nanonets

- Networks of carbon nanotubes enables numerous basic electronic functions at low cost. The durable nature of nanotubes make them suitable to portable devices, like:
  - Electronic paper
  - Flexible touch screens
  - Solar cells
  - Sensors

In the future, you might be reading on a foldable electronic paper, according to a American scientists. Built from thousands of single walled carbon nanotubes
Building Bridges

We must develop common understanding, create lines of communication, and build a stable structure to bridge the cliffs and pass safely through the transition into the nano era.

Summary

- Nanotechnology is inherently an interdisciplinary field that encompasses physics, chemistry, biology, and engineering.

- Recent years have seen significant scientific and technological advances in nanotechnology.

- The federal government and industry are investing heavily in nanotechnology research and development.

- Many future developments and technologies have been promised. Are they realizable?

Useful Internet Sites

7. Discussion about research in nanotechnology - http://www.nano.org/home.php
13. Institute of Nanotechnology - http://www.nano.org/tn
14. What is Nano? Northwestern University, IL - http://www.discovernano.northwestern.edu/whatis
The Next Industrial Revolution

First Revolution
(1780–1840)
- Steam Engine
- Textile Industry
- Mechanical Engineering

Second Revolution
(1840–1890)
- Based in United Kingdom
- England, France, Switzerland
- Railways
- Steel Industry

Third Revolution
(1900–1950)
- Based in United States
- Electric Engine
- Heavy Chemicals
- Automobiles
- Consumer Durables

Fourth Revolution
(1950–Present)
- Based in Pacific Basin
- California, Japan
- Synthetics
- Organic Chemicals (Oil)
- Computers
- Nanotechnology
- Molecular Manufacturing

Fifth Revolution
(2010–Present)

Nanomaterials and Nanostructures in Nature

The best-known biological example of molecular machinery is the ribosome, which is a nanoscale assembler. It acts as a factory of proteins by combining aminoacids together.

Nanomaterials and Nanostructures in Nature

Another example of the role of nanostructures in nature is photosynthesis. Photosynthesis happens in the chloroplasts. Each reaction center is composed by 10,000 atoms and 200 pigments. Efficiency of the process about 95%.

Nanomaterials and Nanostructures in Nature

A talented mollusk is the mussel. Mussels need to use waterproof adhesive to anchor themselves to a solid surface.

They need to produce a glue that sticks under water!
Nanomaterials and Nanostructures in Nature

Geckos have an extraordinary ability to adhere to surfaces. This behavior is due to keratin hairs, 200 nm in diameter, that cover their feet. Each hair produces a very small force of $10^{-7}$ N/. Half a million of these tiny hairs produce an extremely strong adhesive force, as high as 10N/cm$^2$.

Hierarchical Structure of Gecko Feet

From K. Autumn, American Scientist, 2006

Nanomaterials and Nanostructures in Nature

The brain's neurons have thousands of connections (while a computer's transistor have only a few). The brain spends $10^{-15}$ J per operation, while a computer spends $10^{-7}$ J per operation.

Nanomaterials in Art

Chartres Cathedral

Lycargus Cup

Co oxide
Silica particles