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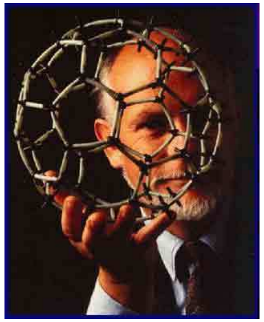
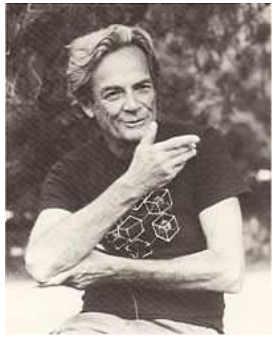


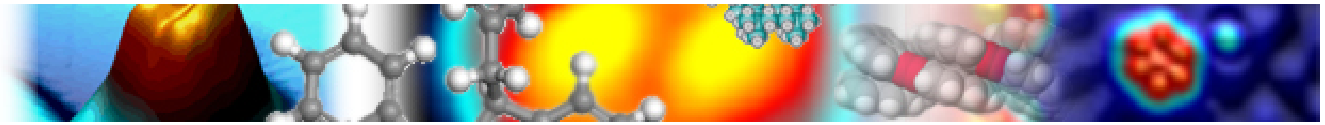


Nanoscience: A historical perspective

R. Díez Muiño and P. M. Echenique

Lecture Notes

Fall 2007



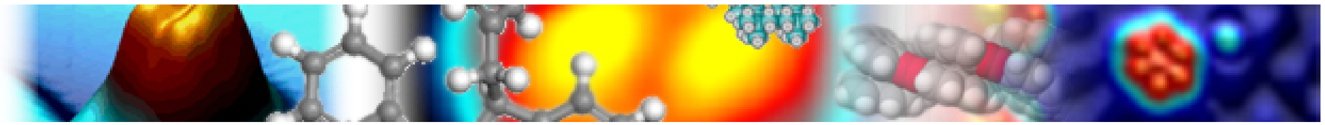
THE SCALE OF THINGS

THE SCALE OF THINGS

1 nano = 10^{-9}

1 nanometer = 10^{-9} meters

The root comes from the Greek for **dwarf**
The prefix was formally adopted in the late 1940's to mean 10^{-9}



Full Range of Sizes

Sixty Orders of Magnitude
Life in Middle Region

Planck Length
10^{-35} m

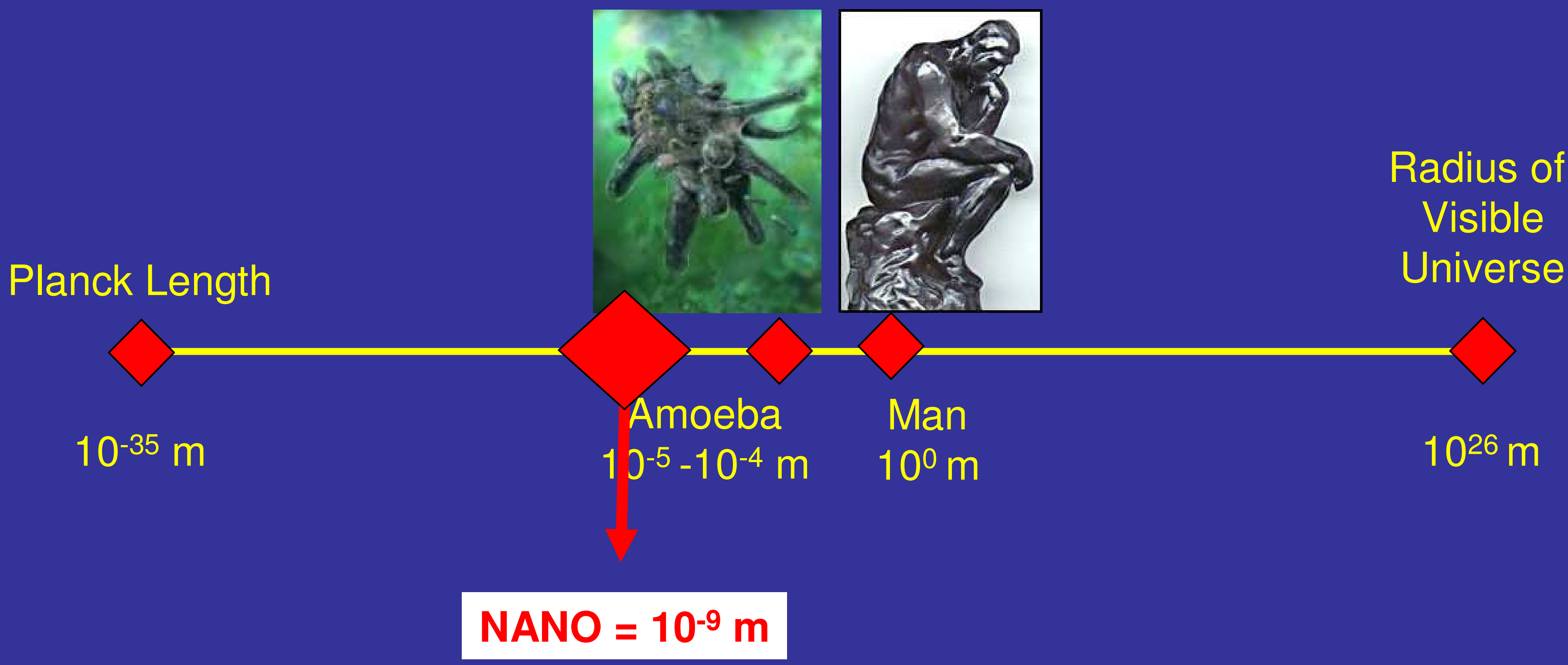
Amoeba
10^{-5} - 10^{-4} m

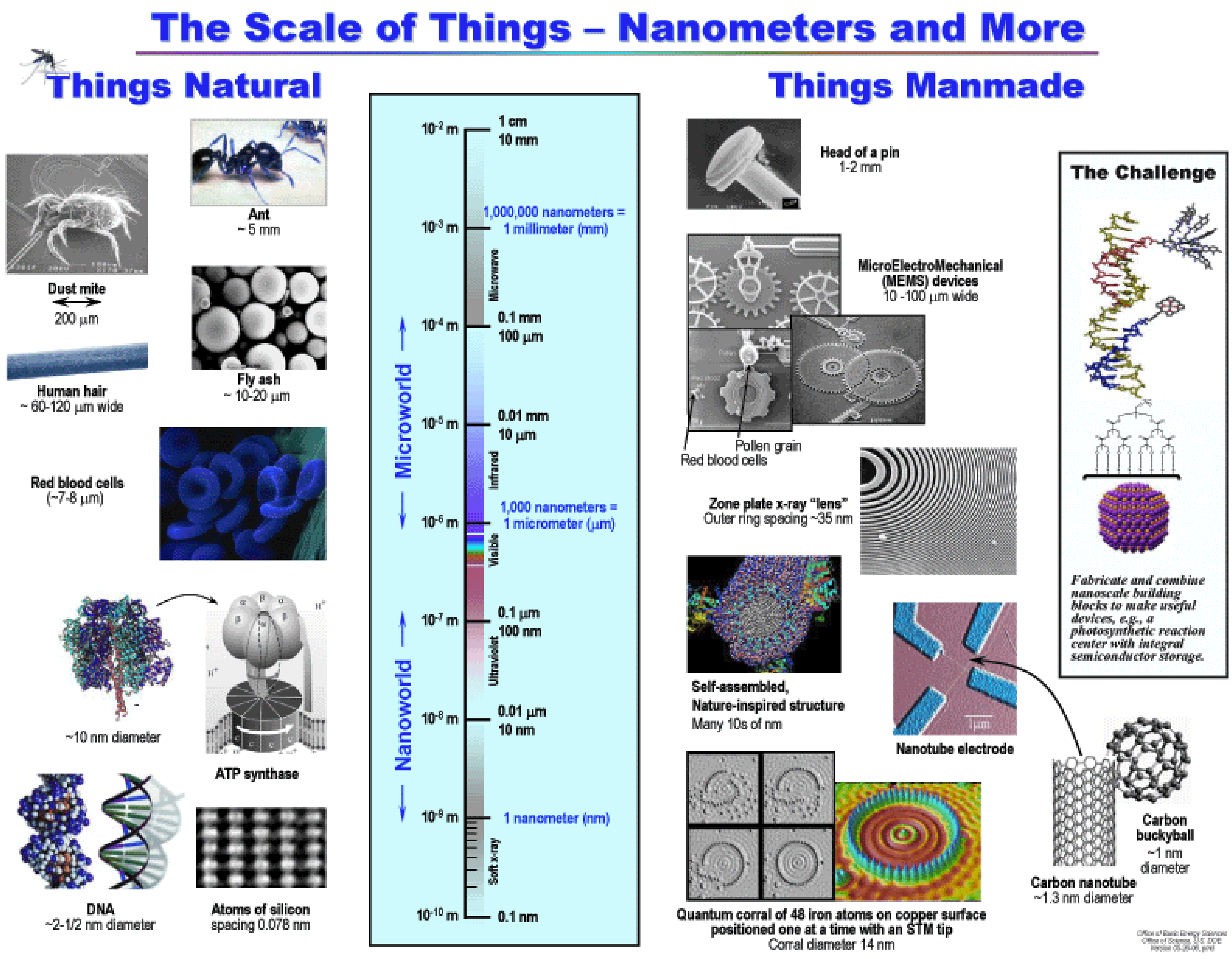
Man
10^{0} m

Radius of Visible Universe
10^{26} m

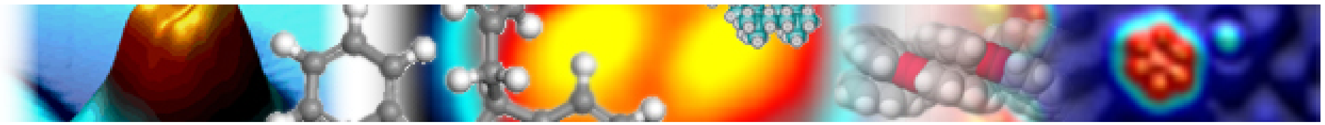
Full Range of Sizes

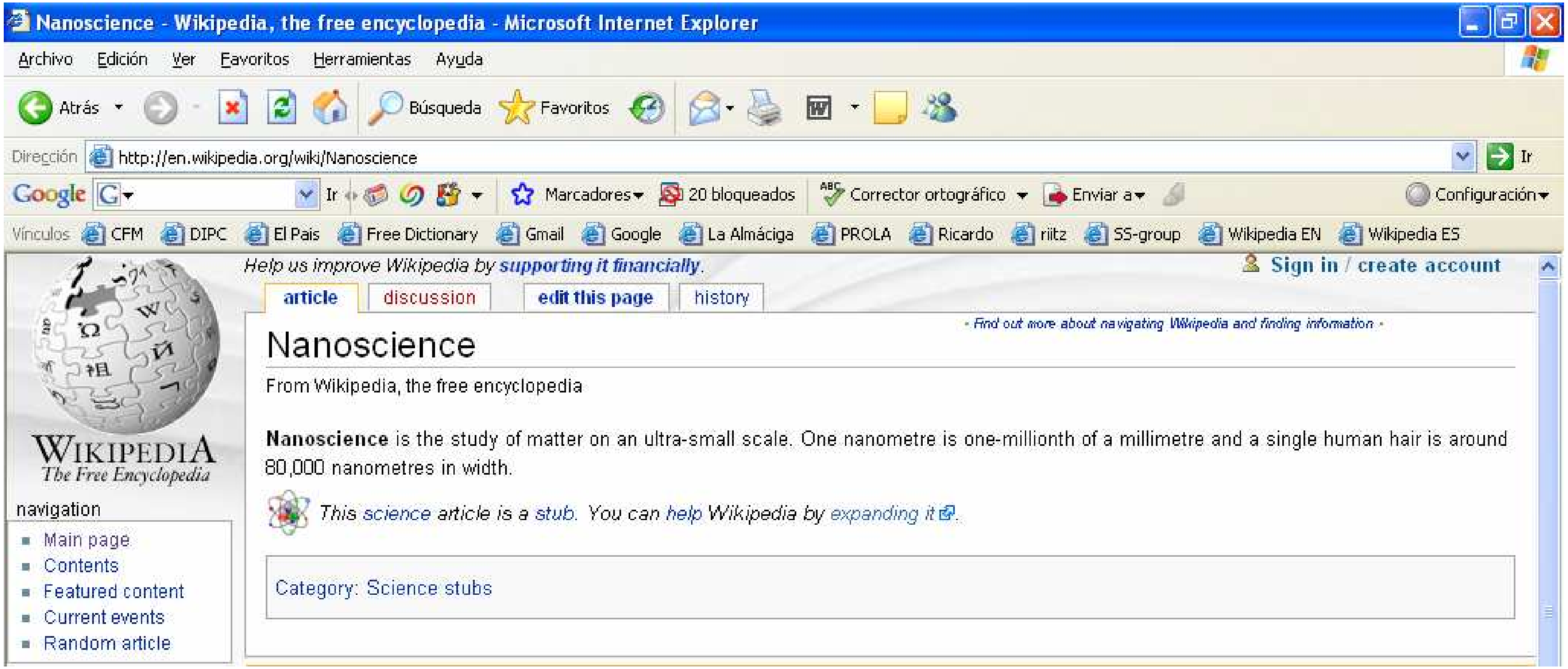
Sixty Orders of Magnitude
Life in Middle Region




The Scale of Things – Nanometers and More
Things Natural
Things Manmade
Dust mite
200 µm
Ant
~ 5 mm
Human hair
~ 60-120 µm wide
Fly ash
~ 10-20 µm
Red blood cells
(~7-8 µm)
~10 nm diameter
ATP synthase
DNA
~2-1/2 nm diameter
Atoms of silicon
spacing 0.078 nm
10^{-2} m
1 cm
10 mm
1,000,000 nanometers =
1 millimeter (mm)
10^{-3} m
Microwave
10^{-4} m
0.1 mm
100 µm
Microworld
10^{-5} m
0.01 mm
10 µm
Infrared
1,000 nanometers =
1 micrometer (µm)
10^{-6} m
Visible
10^{-7} m
0.1 µm
100 nm
Ultraviolet
Nanoworld
10^{-8} m
0.01 µm
10 nm
10^{-9} m
1 nanometer (nm)
Soft x-ray
10^{-10} m
0.1 nm
Head of a pin
1-2 mm
MicroElectroMechanical
(MEMS) devices
10 -100 µm wide
Pollen grain
Red blood cells
Zone plate x-ray "lens"
Outer ring spacing ~35 nm
Self-assembled,
Nature-inspired structure
Many 10s of nm
Nanotube electrode
Quantum corral of 48 iron atoms on copper surface
positioned one at a time with an STM tip
Corral diameter 14 nm
Carbon nanotube
~1.3 nm diameter
Carbon buckyball
~1 nm
diameter
The Challenge
Fabricate and combine nanoscale building blocks to make useful devices, e.g., a photosynthetic reaction center with integral semiconductor storage.

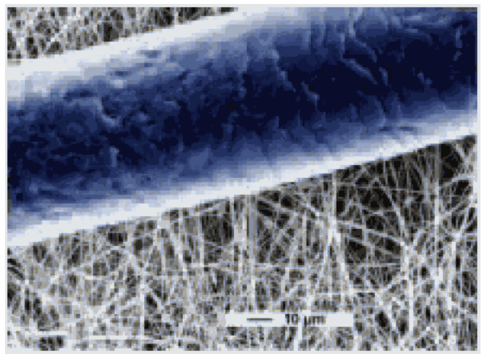
DEFINITION OF NANOSCIENCE (AND NANOTECHNOLOGY)





human hair (80,000 nm)

nanofibrils (80 nm)



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Nanotechnology

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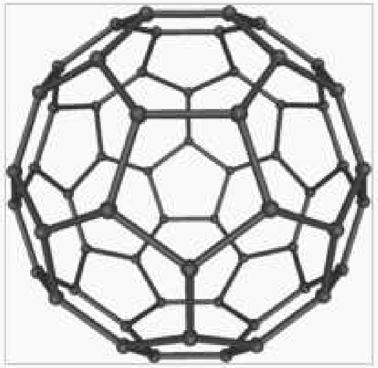

Buckminsterfullerene C_{60}, also known as the buckyball, is the simplest of the carbon structures known as fullerenes. Members of the fullerene family are a major subject of research falling under the nanotechnology umbrella.

Nanotechnology refers broadly to a field of applied science and technology whose unifying theme is the control of matter on the molecular level in scales smaller than 1 micrometre, normally 1 to 100 nanometers, and the fabrication of devices within that size range.

It is a highly multidisciplinary field, drawing from fields such as applied physics, materials science, colloidal science, device physics, supramolecular chemistry, and even mechanical and electrical engineering. Much speculation exists as to what new science and technology may result from these lines of research. Nanotechnology can be seen as an extension of existing sciences into the nanoscale, or as a recasting of existing sciences using a newer, more modern term.

Two main approaches are used in nanotechnology. In the "bottom-up" approach, materials and devices are built from molecular components which assemble themselves chemically by principles of molecular recognition. In the "top-down" approach, nano-objects are constructed from larger entities without atomic-level control. The impetus for nanotechnology comes from a renewed interest in colloidal science, coupled with a new generation of analytical tools such as the atomic force microscope (AFM), and the scanning tunneling microscope (STM). Combined with refined processes such as electron beam lithography and molecular beam epitaxy, these instruments allow the deliberate manipulation of nanostructures, and led to the observation of novel phenomena.

Examples of nanotechnology in modern use are the manufacture of polymers based on molecular structure, and the design of computer chip layouts based on surface science. Despite the great promise of numerous nanotechnologies such as quantum dots and nanotubes, real commercial applications have mainly used the advantages of colloidal nanoparticles in bulk form, such as suntan lotion, cosmetics, protective coatings, and stain resistant clothing.

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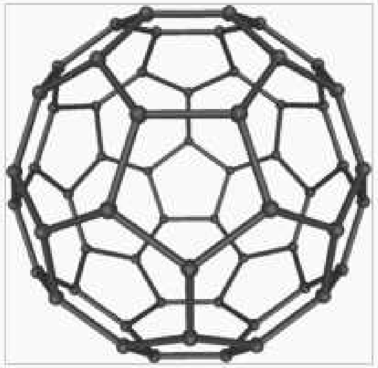

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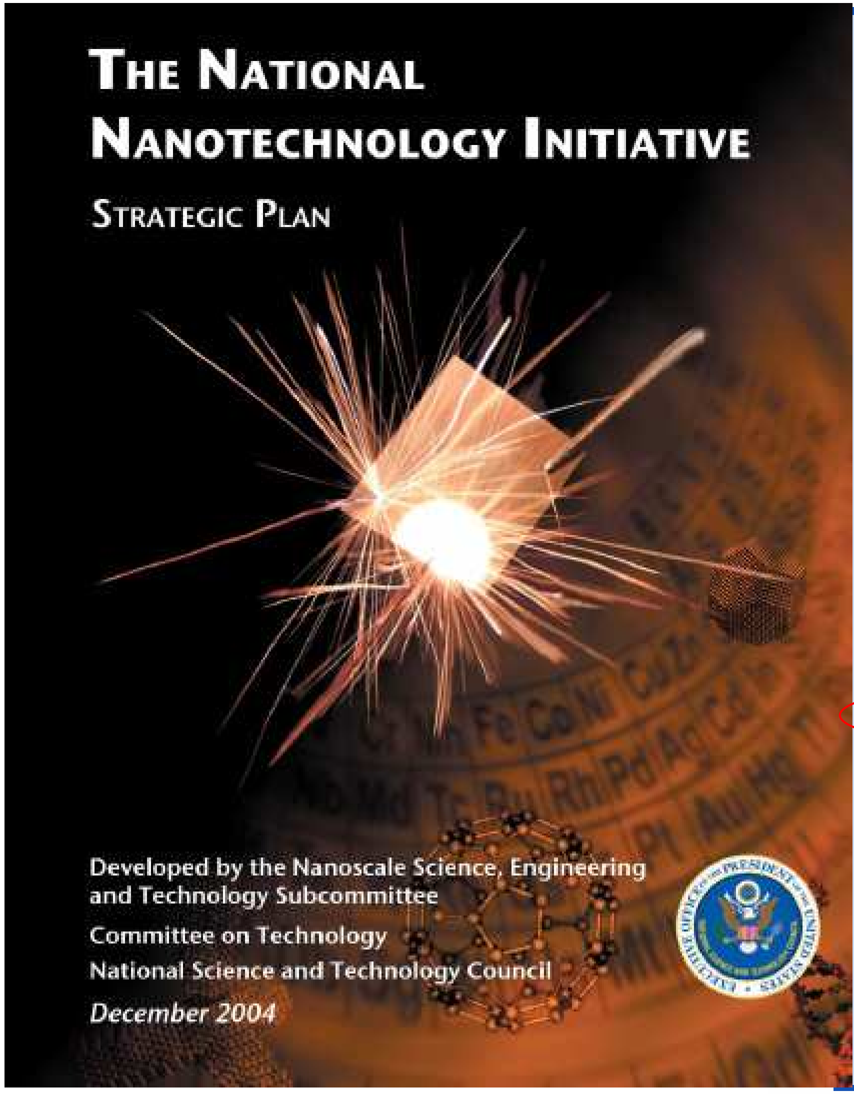


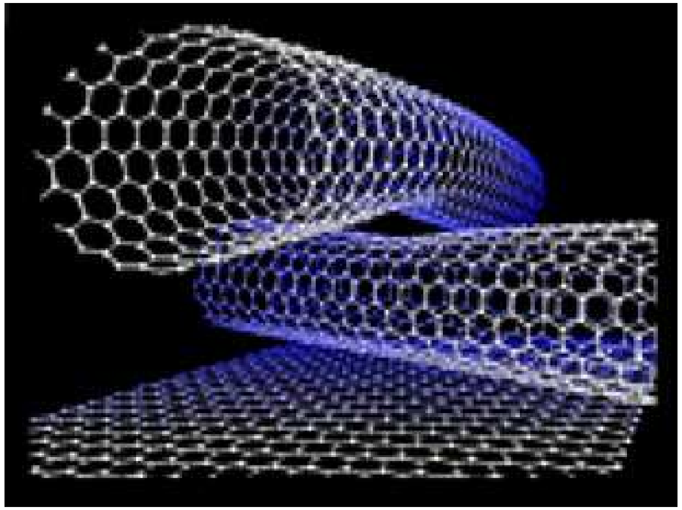
What is Nanotechnology?

Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications. A nanometer is one-billionth of a meter; a sheet of paper is about 100,000 nanometers thick. Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale.

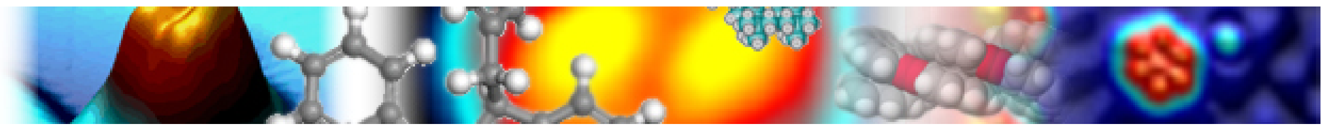
At this level, the physical, chemical, and biological properties of materials differ in fundamental and valuable ways from the properties of individual atoms and molecules or bulk matter. Nanotechnology R&D is directed toward understanding and creating improved materials, devices, and systems that exploit these new properties.

Nanotechnologies are the design, characterization, production and application of structures, devices and systems by controlling shape and size at nanometer scale

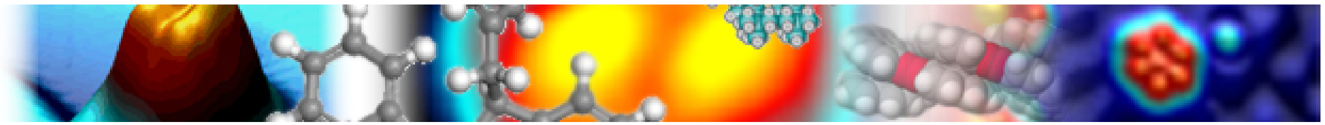
(Royal Society, London, UK)

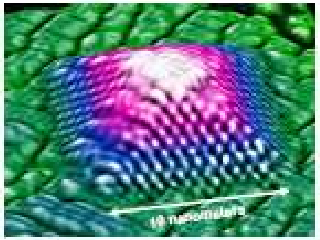


- Nanoscale = 10^{-9} - 10^{-7} meters
- Properties of matter differ from larger scale (solids)
- Understanding and control of matter in this scale
- Multidisciplinarity → Interdisciplinarity?



BENEFITS OF NANOTECHNOLOGY





National Nanotechnology Initiative (NNI)

"My budget supports a major new National Nanotechnology Initiative, worth $500 million.... the ability to manipulate matter at the atomic and molecular level. Imagine the possibilities: materials with ten times the strength of steel and only a small fraction of the weight -- shrinking all the information housed at the Library of Congress into a device the size of a sugar cube -- detecting cancerous tumors when they are only a few cells in size. Some of our research goals may take 20 or more years to achieve, but that is precisely why there is an important role for the federal government."

--President William J. Clinton

January 21, 2000

California Institute Of Technology

Benefits of Nanotechnology

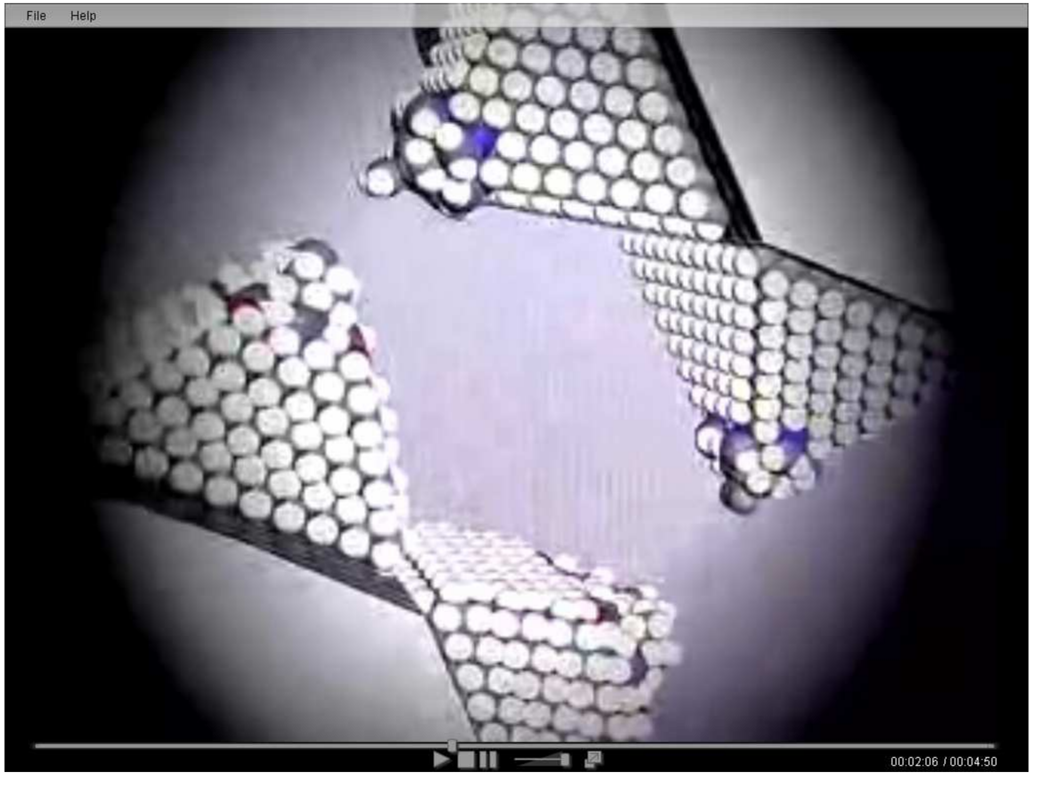
The Foresight Nanotechnology Challenges address critical needs that could be met by developing a range of near and long term nanotechnology solutions. They include:

1) meeting global energy needs through more efficient generation, storage and distribution,
2) providing abundant clean water through improved water purification and filtration,
3) increasing health and longevity of human life through medical diagnostics, drug delivery and customized therapy,
4) maximizing the productivity of agriculture through precision farming, targeted pest management and the creation of high yield crops,
5) making powerful information technology available everywhere through reduced cost and higher performance of memory, networks, processors and components,
6) enabling the development of space resources through improved fuels, as well as smart materials and environments.

Source: Foresight Institute

Benefits of Nanotechnology

Nanofactory



Benefits of Nanotechnology

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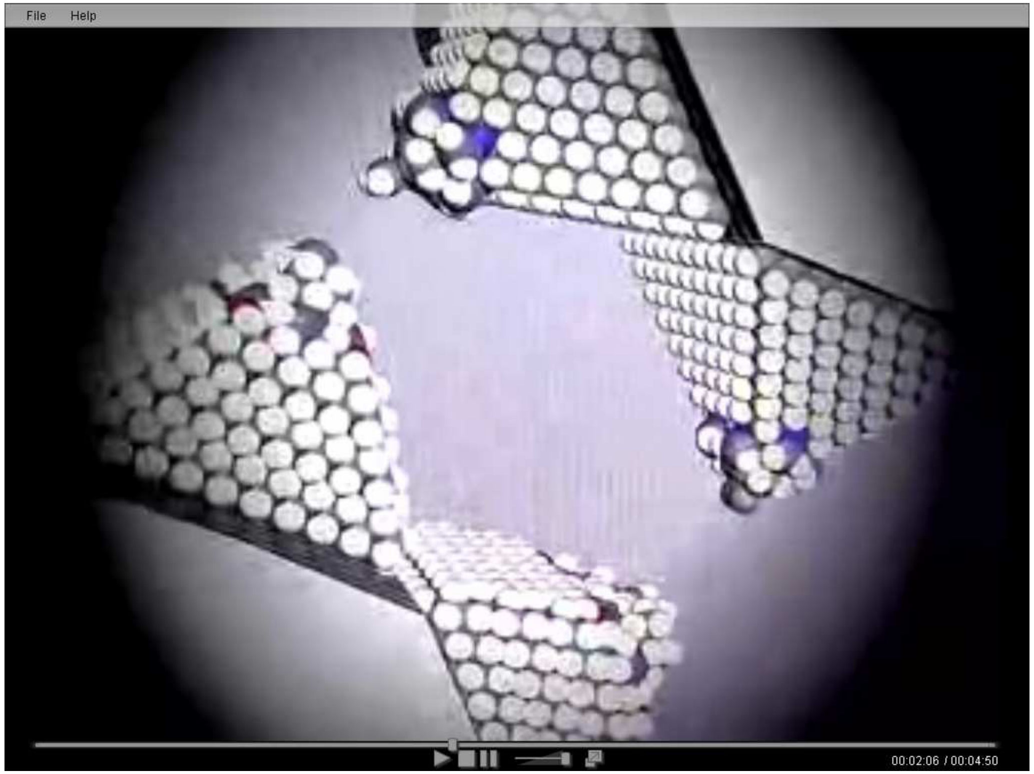


Science-Fiction,
not Science!!

While nanotechnology is in the **“pre-competitive” stage** (meaning its applied use is limited), nanoparticles are being used in a number of industries. Nanoscale materials are used in electronic, magnetic and optoelectronic, biomedical, pharmaceutical, cosmetic, energy, catalytic and materials applications. Areas producing the greatest revenue for nanoparticles reportedly are chemical-mechanical polishing, magnetic recording tapes, sunscreens, automotive catalyst supports, biolabeling, electroconductive coatings and optical fibers.

Current Use of NanoProducts

Materials: nanoparticles can be introduced into many existing materials, making them stronger or changing their conductive properties. For instance, wear-resistant coatings can be used in everything, from personal cars to heavy industrial machinery.

Bio: enhancement of biological imaging for medical diagnostics and drug discovery (quantum dots)

Electronics: latest display technology for laptops, cell phones, digital cameras and other uses are made of nanostructured polymer films (OLEDs)

Nanocatalysis, where the large surface area per unit volume of nanosized catalysts enhances reactions (oil and car industries)

Environment: filters made of nanoparticles also have been found to be excellent for liquid filtration and large-scale water purification.

Future Applications

Advanced drug delivery systems, including implantable devices that automatically administer drugs and sensor drug levels

Medical diagnostic tools, such as cancer tagging mechanisms and lab-on-a-chip, real time diagnostics for physicians

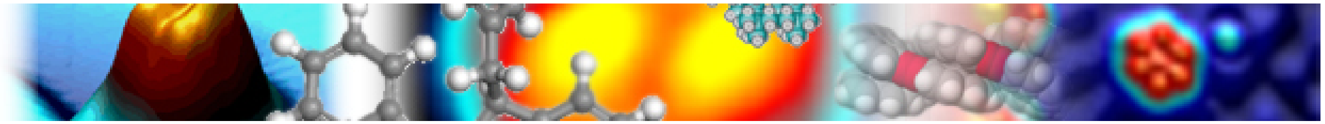
Cooling chips or wafers to replace compressors in cars, refrigerators, air conditioners and multiple other devices, utilizing no chemicals or moving parts

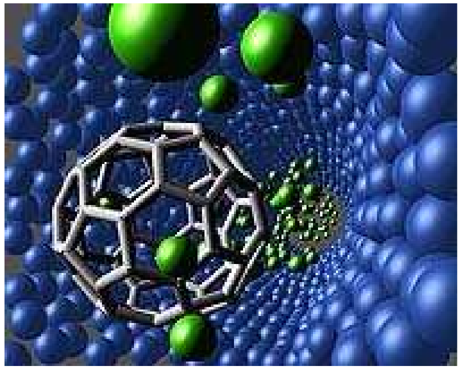
Sensors for airborne chemicals or other toxins

Photovoltaics (solar cells), fuel cells and portable power to provide inexpensive, clean energy

New high-performance materials.

RISKS
OF NANOTECHNOLOGY

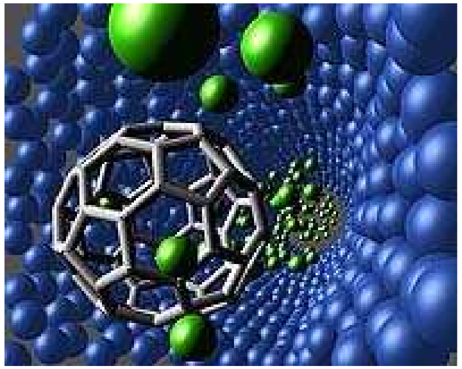




Risks of Nanotechnology

The risks associated with passive compounds in the less than 100 nanometer size range concern their ability to be inhaled, absorbed through the skin, or to pass through biological compartment barriers such as the blood brain barrier. They thus pose a range of potential health and environmental risks that are associated with their potential toxicity or mutagencity in their interactions with biological systems.

Source: Foresight Institute



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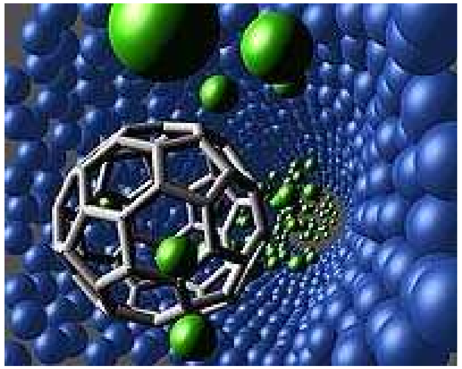
If weaponized versions of Molecular Nanotechnology are developed, they may not fall under existing arms-control treaties. Adding particular weapons related applications of Molecular Nanotechnology to the list of technologies covered in Chemical, Biological and Nuclear Weapons treaties may be appropriate in certain cases.

Source: Foresight Institute



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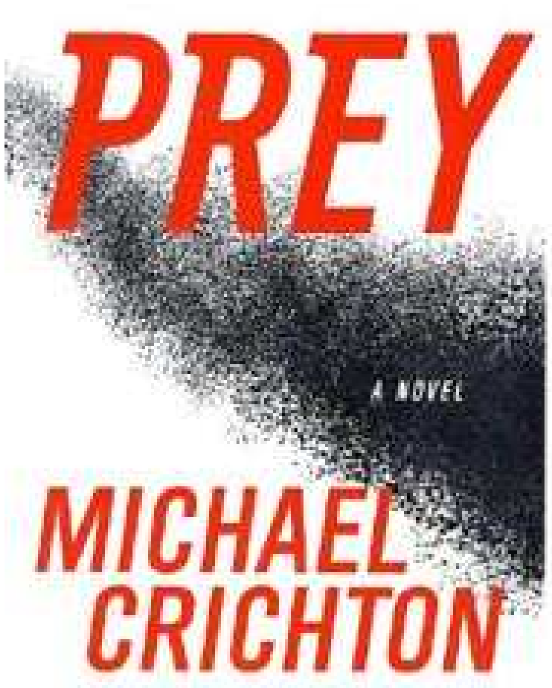
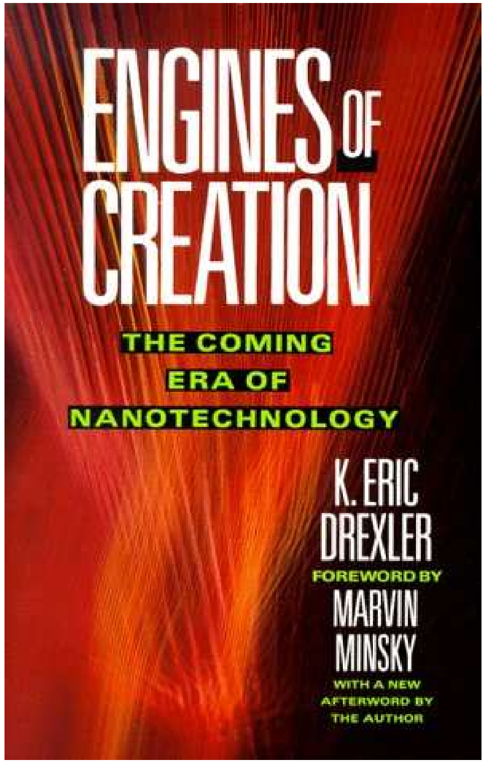
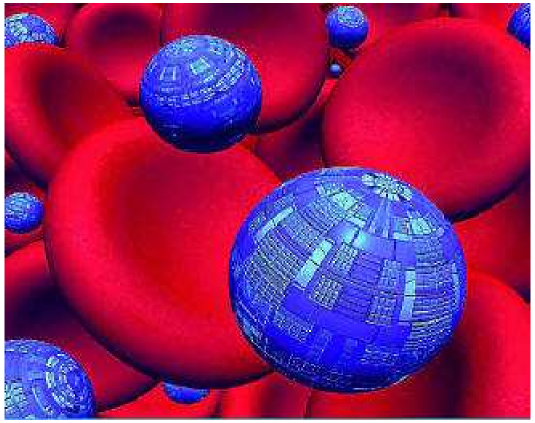
However, a determined and sophisticated group of terrorists or "non state entities" could potentially, with considerable difficulty, specifically engineer systems to become *autonomous replicators* able to proliferate in the natural environment, either as a nuisance, a specifically targeted weapon, or in the worst case, a weapon of mass destruction.

Source: Foresight Institute

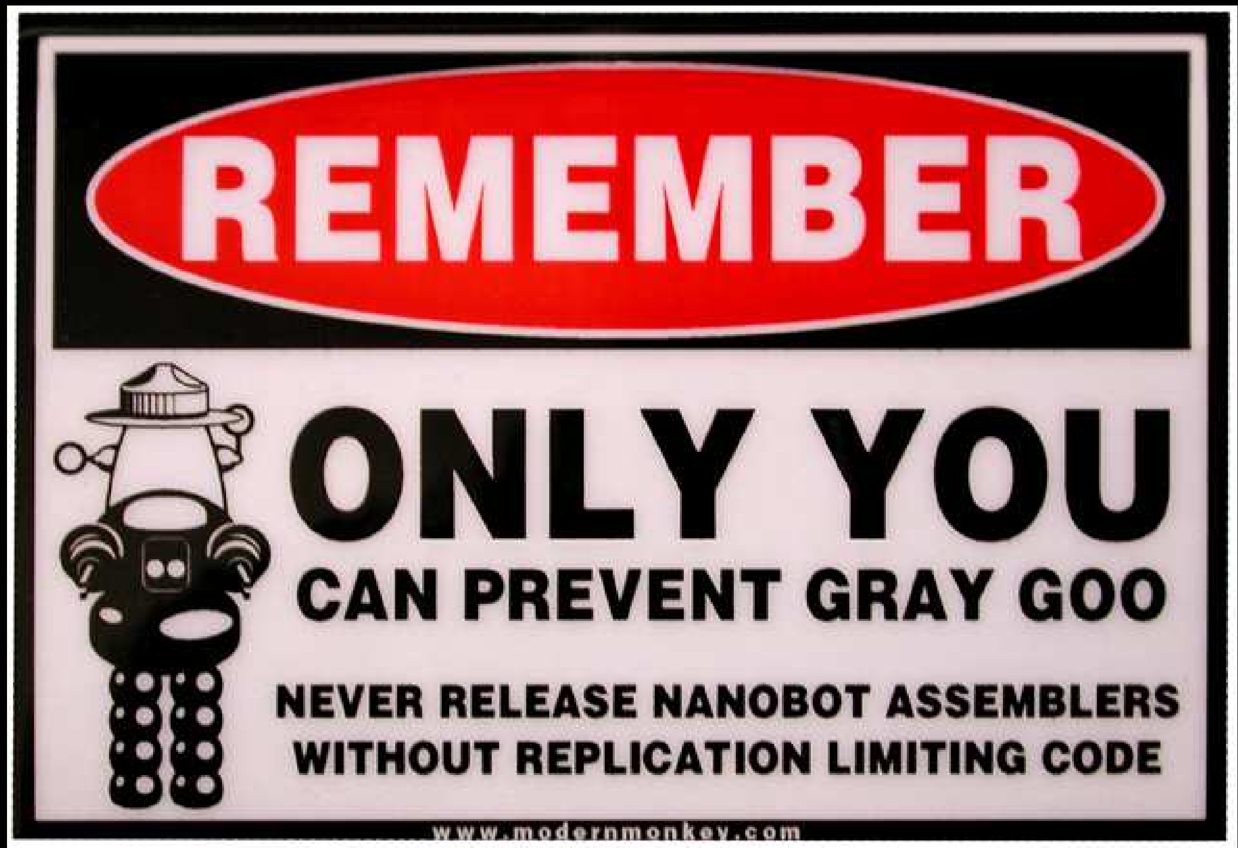
Risks of Nanotechnology







grey goo scenario:
out-of-control self-replicating robots
consume all living matter on Earth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ONLY YOU
CAN PREVENT GRAY GOO
NEVER RELEASE NANOBOT ASSEMBLERS
WITHOUT REPLICATION LIMITING CODE
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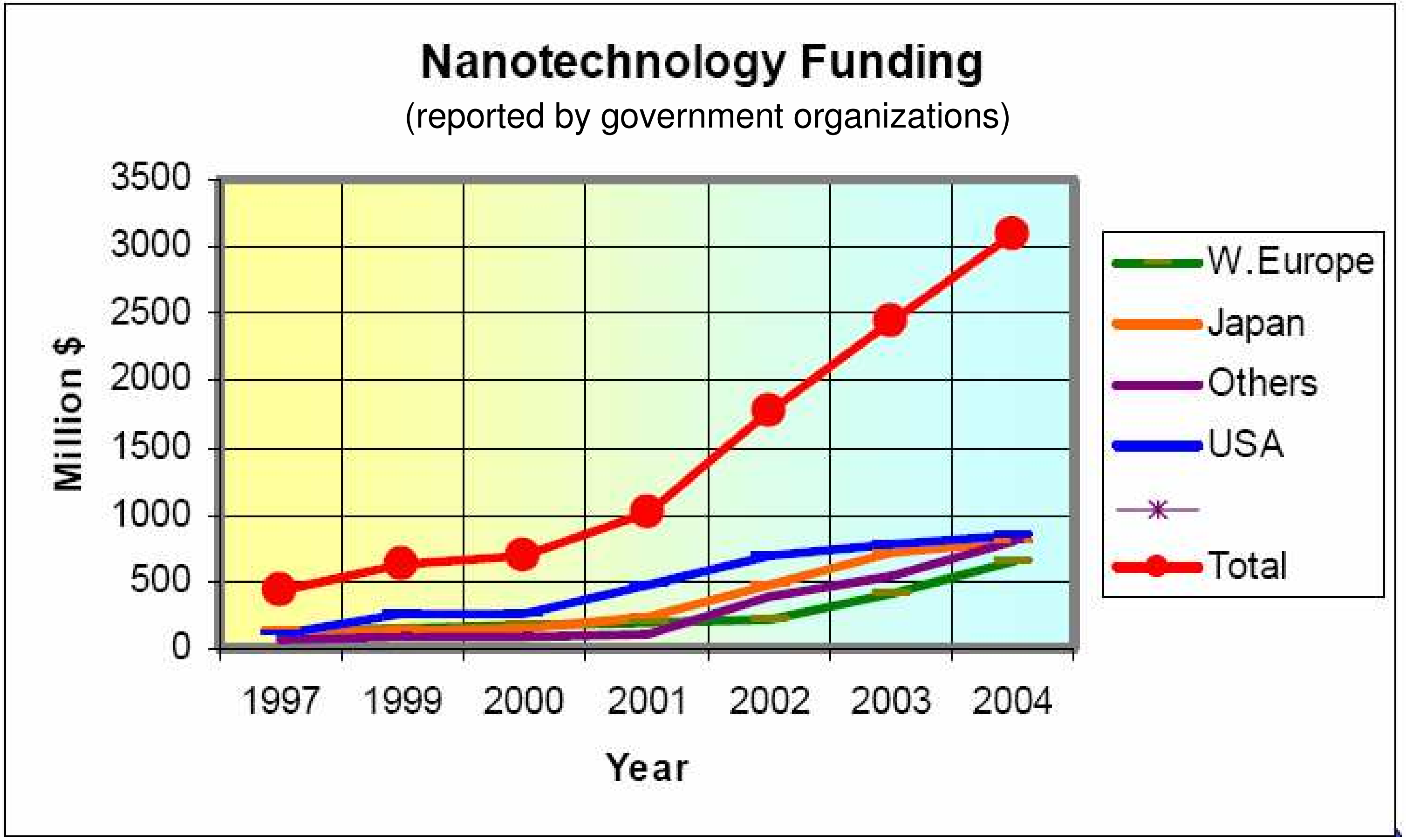
SOCIETAL CONSEQUENCES OF NANOTECHNOLOGY

World-wide Nanotechnology $



Source: International Technology Roadmap for Semiconductors (ITRS)

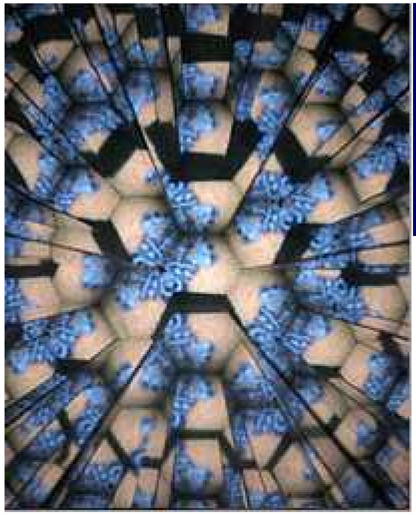
Word-wide Nanotechnology Funding ($)

	1997	1999	2000	2001	2002	2003	2004
W.Europe	126	151	179	200	225	400	650
Japan	120	135	157	245	465	720	800
Others	70	83	96	110	380	550	800
USA	116	255	270	466	697	770	849
Total	432	624	702	1022	1767	2440	3099
Cum	432	1056	1758	2780	4547	6987	10086

Nan°arte

A Paperkut project. In collaboration with the Physics Department at the Politecnico di Torino.

'Beyond Hercules Columns' artwork.
Created by the FESEM (Field Effect Scanning Electron Microscope) instrument.

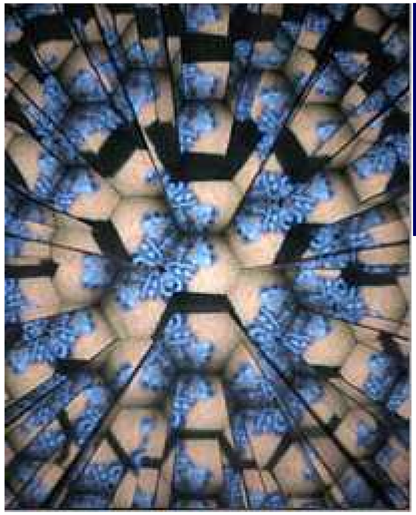


What are the potential applications for nanotechnology in medical science?

What are some examples of the use of nanotechnology in practical applications today?

What about the dangers of novel, tiny molecular assemblages interacting in unforeseen ways with the biota?

'Nano: where art and science meet'
LA County Museum Exhibit
Questions raised by general public



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What are the theological implications of nanotechnology?

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Societal Interactions

- **Public Acceptance/Resistance**
  - Post-WW II Ambivalence to Technology
  - Complexity causes Uncertainty: Science vs. Commonsense
  - A Cautionary Tale -- Genetically-Modified Food

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- **Who Decides? Control and Public Participation**

Societal Interactions

Nanotechnology at Brown University

Ethical Challenges (many of them linked to 'bio')

"Playing God?" Eugenics? Essence of Humanity?

Risk and Harm: Patients and Testing?

Values: Individual or Community?

Control over Personal Information?

Equally Distributing Costs & Benefits

Access and Availability of Results

Education Center

Nanotechnology is a multidisciplinary field of discovery. Scientists working in physics, chemistry, biology, engineering, information technology, metrology, and other fields are contributing to today's research breakthroughs.

The worldwide workforce necessary to support the field of nanotechnology is estimated at **2 million** by **2015**. How does the U.S. educational system train these workers and how do students choose the appropriate educational path for their interests?

US National Nanotechnology Initiative

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US National Nanotechnology Initiative

Education and training are crucial!!!

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US National Nanotechnology Initiative

Education of Informed Scientists and Engineers

↓

Dialogue of Researchers with Society

↓

Responsibility

Summarizing…

Qualitative new step in miniaturization…

- Basic scientific breakthroughs
- New technologies

Summarizing…

Qualitative new step in miniaturization…

- Basic scientific breakthroughs
- New technologies

… with economic consequences
(but always balance the hype)

- Industrial manufacturing: new materials and products
- Medicine: diagnosis and therapies
- Sustainability: environment (solar cells, catalysts, efficient lighting, etc.)
- Nanocomputing: extending Moore's law