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Why is nanoscience attracting so much interest?

- The fundamental properties of matter change at the nanoscale.
- The properties of atoms and molecules are not governed by the same physical laws as larger objects, but by “quantum mechanics”.

Image: Fanny Beron, École Polytechnique de Montréal, Canada

Mr Miguel Ângel Fernández Vindel, Universidad Autonoma de Madrid/Spain
What’s interesting about nanoscale?

• The physical and chemical properties of nanoparticles can be quite different from those of larger particles of the same substance.

• Altered properties can include but are not limited to colour, solubility, material strength, electrical conductivity, magnetic behavior, mobility (within the environment and within the human body), chemical reactivity and biological activity.

Image: C. Menozzi, G.C. Gazzadi, S3 (INFM-CNR), Modena. Artwork: Lucia Covi
Why nanomaterials?

“Imagine dissociating a human body into its most fundamental building blocks. We would collect a considerable portion of gases, namely hydrogen, oxygen, and nitrogen; sizable amounts of carbon and calcium; small fractions of several metals such as iron, magnesium, and zinc; and tiny levels of many other chemical elements. The total cost of these materials would be less than the cost of a good pair of shoes. Are we humans worth so little?

Obviously not, mainly because it is the arrangement of these elements and the way they are assembled that allow human beings to eat, talk, think, and reproduce. In this context, we could ask ourselves: What if we could follow nature and build whatever we want, atom by atom and/or molecule by molecule?”
What is so special about nanotechnology?

- it is an incredibly broad, interdisciplinary field. It requires expertise in physics, chemistry, materials science, biology, mechanical and electrical engineering, medicine, and their collective knowledge.
- it is the boundary between atoms and molecules and the macro world, where ultimately the properties are dictated by the fundamental behavior of atoms.
- it is one of the final great challenges for humans, in which the control of materials at the atomic level is possible.
The aim of the course

This course is aimed at the introduction of nanomaterials and nanotechnologies:

- Classification of nanomaterials
- Size effects
- Features of nanostructures
- Physical background of nanostructures
- Techniques of synthesis of nanomaterials
- Tools of the nanoscience
- Applications of nanomaterials and technologies
Grading policy

- **Method of grading**
  The course grade is based on numerical scores that include a presentation (P) and written assignments (essays) (T), and a cumulative written final exam (E).

- **Grading criteria**
  - Course paper presentation (P): The comprehensive understanding of the chosen topic is evaluated. Students giving presentations should be able to answer any question about a topic or fact that he or she brings up in the presentation (within reason of course!). You brought it up— you answer it! Grading is ranked 1 – 5.
  - Written assignments (essays) (T) – written short essays on understanding of the materials of lecture (16 essays altogether). There are no absolutely right or wrong answers, and grading is mostly based on effort. Grading is ranked 1 – 5.
  - Final exam (E) – written cumulative exam consisting of 20 questions.
Final grading

- **The final grade** is according to the following weighting system:
  - Essays 30%
  - Course paper presentation 20%
  - Final exam 50%
OUTLINE

- How big are small things or how small are big ones?
- What is nanotechnology?
- Can we see invisible?
- Will we live forever?
- Do we need nano?
How big is nanometer?

Source: http://www.materialsworld.net/nclt/docs/Introduction%20to%20Nano%201-18-05.pdf
A nanometer (nm) is one thousand millionth of a meter ($10^{-9}$).

For comparison, a red blood cell is approximately 7,000 nm wide. A water molecule is almost 0.3 nm across. 10 hydrogen atoms lined up measure about 1 nm. A grain of sand is 1 million nm, or 1 millimeter, wide.
The scale of things

A soccer ball with a diameter
$\sim 30 \text{ cm} = 3 \times 10^{-1} \text{ m}$. 

The width of a human hair (here placed on a microchip at the white arrow) is roughly 10^{4} times, i.e.
$\sim 30 \mu m = 3 \times 10^{-5} \text{ m}$. 

The diameter of a carbon nanotube (here placed on top of some metal electrodes) is yet another $10^{4}$ times smaller, i.e.
$\sim 3 \text{ nm} = 3 \times 10^{-9} \text{ m}$. 
Length scales

Astronomical scale
- Nearest galaxy (2 \times 10^{22} \text{ m})
- 1 light year (9.5 \times 10^{15} \text{ m})
- Earth–sun distance (1 AU \times 1.5 \times 10^{11} \text{ m})
- Earth–moon distance (3.8 \times 10^8 \text{ m})

Terrestrial scale
- Circumference of the Earth (4.2 \times 10^7 \text{ m})
- Thickness of the Earth’s crust (3 \times 10^4 \text{ m})
- Height of Mt. Everest (8 \times 10^3 \text{ m})
- Depth of deep oceans (5 \times 10^3 \text{ m})

Human scale
- League (3 miles, 4.8 \times 10^3 \text{ m})
- Furlong (22 yards, 2 \times 10^2 \text{ m})
- Foot (3 \times 10^{-1} \text{ m})
- Inch (ell) (2.54 \times 10^{-2} \text{ m})
- Diameter of a hair (2 \times 10^{-6} \text{ m})

Molecular and atomic scale
- Molecular scale
- Atomic scale

Subatomic scale
- Electron
- Neutron
- Proton

Metres
- \text{zetta} (-18)
- \text{exam} (-15)
- \text{peta} (-12)
- \text{tera} (-9)
- \text{giga} (-6)
- \text{mega} (-3)
- \text{kilo} (-1)
- \text{hecto} (-2)
- \text{deca} (-3)

Infrastructural engineering
- Road systems
- Rail systems
- Water distribution systems
- Sewage systems

Conventional engineering
- Shipping
- Trains, aircraft
- Cars, trucks
- Household products
- Precision instruments
- Conventional electronics

Nanoengineering
- Microelectronic components
- Nanostructured solids
- Nanoparticles and emulsions
- Thin films, multilayers
- Carbon nanotubes
- Amorphous materials

M. Ashby, P. Ferreira, D. Schodek; Nanomaterials, Nanotechnologies and Design; Copyright 2009 Elsevier Ltd.
What is nanoscale science?

- The study of objects and phenomena at a very small scale, roughly 1 to 100 nanometers (nm)
- We define **nanoscience** as the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale;
- and **nanotechnologies** as the design, characterisation, production and application of structures, devices and systems by controlling shape and size at the nanometer scale.
What is nanotechnology?

“The purposeful engineering of matter at scales of less than 100 nanometers to achieve size-dependent properties and functions.”


Not “nano by accident”

Really small  Not just “small”; “small and different”

The design, characterization, production, and application of structures, devices, and systems by controlled manipulation of size and shape at the nanometer scale (atomic, molecular, and macromolecular scale) that produces structures, devices, and systems with at least one novel/superior characteristic or property.
There’s Plenty of Room at the Bottom:
An Invitation to Enter a New Field of Physics

Richard Feynman
Cal Tech, 1959

“People tell me about miniaturization, and how far it has progressed today. They tell me about electric motors that are the size of the nail on your small finger. And there is a device on the market, they tell me, by which you can write the Lord's Prayer on the head of a pin. But that's nothing; that's the most primitive, halting step in the direction I intend to discuss. It is a staggeringly small world that is below. In the year 2000, when they look back at this age, they will wonder why it was not until the year 1960 that anybody began seriously to move in this direction. *Why cannot we write the entire 24 volumes of the Encyclopedia Brittanica on the head of a pin?*

This goal requires patterning at the 10 nanometer scale.
Historical milestones

“It would be, in principle, possible (I think) for a physicist to synthesize any chemical substance that the chemist writes down. . . . Put the atoms down where the chemist says, and so you make the substance.” - Richard Feynman, *There’s Plenty of Room at the Bottom* (1959).

Don Eigler and Erhard Schweizer spelled “IBM” with 35 xenon atoms, 1989. This logo could fit 350 million times in the area at the point of a pin.

"We cannot afford certain types of accidents" - Eric Drexler, *Engines of creation*, 1986, the book where the term "grey goo" was coined.

“My budget supports a major new National Nanotechnology Initiative, worth $500 million. More than 40 years ago, Caltech’s own Richard Feynman asked, ‘What would happen if we could arrange the atoms one by one the way we want them?’” - President Clinton, Caltech (2000).
How can we get to nano?

New Tools!

- **The naked eye can see to about 20 microns**
  - A human hair is about 50-100 microns thick
- **Light microscopes let us see to about 1 micron**
  - Bounce light off of surfaces to create images

Optical microscopes use light to see objects as small as 200 nm. Invented in 1600s.

Sources: [http://www.cambridge.edu.au/education/PracticelITBook2/Microscope.jpg](http://www.cambridge.edu.au/education/PracticelITBook2/Microscope.jpg)
[http://news.bbc.co.uk/mediathread/7700000/images/764022_red_blood_cells300.jpg](http://news.bbc.co.uk/mediathread/7700000/images/764022_red_blood_cells300.jpg)
Electrons help to see small sized objects

- **Scanning electron microscopes (SEM)**, invented in the 1930s, let us see objects as small as 10 nanometers
  - Bounce electrons off of surfaces to create images
  - Higher resolution due to small size of electrons

Greater resolution to see things like blood cells in greater detail

Sources:  
- http://www.biotech.iastate.edu/facilities/BMF/images/SEMFaye1.jpg  
- http://cgee.hamline.edu/see/questions/dp_cycles/cycles_bloodcells_bw.jpg
New way to see things

- Scanning probe microscopes, developed in the 1980s, give us a new way to “see” at the nanoscale.
- We can now see really small things, like atoms, and move them too!

- Allowed us to image individual atoms
- Small tip (a few atoms in size) is held above the conductive surface.
  Electrons “tunnel” between the probe and surface (Quantum Mechanics).
- The tip is scanned across the surface measuring the current to create the image.
Can we make small devices?

In 1965, Gordon E. Moore (co-founder of Intel) observed that the number of transistors squeezed onto a computer chip roughly \textbf{every 18 months}.

A modern computer chip contains more than \textbf{10 million transistors}, and the smallest wire width are incredibly small, now entering the sub 100 nm range. Just as the American microprocessor manufacturer, Intel, at the end of 2003 shipped its first high-volume 90 nm line width production to the market, the company announced that it expects to ramp its new 65 nm process in 2005 in the production of static RAM chips. Nanotechnology with active components is now part of ordinary consumer products.
Historical background

"No Exponential is Forever ... but We Can Delay ‘Forever’,”
Moor’s law

“Cramming More Components Onto Integrated Circuits”
Author: Gordon E. Moore
Publication: Electronics, April 19, 1965
Where are nanoworld boundaries?

At some point, the laws of physics will make it impossible to keep downsizing microelectronics at this rate.

Decrease in size results in the particles physical – chemical properties changing and, consequently, the properties of nano-materials are changed dramatically and sometime cordially.
Size effects

Internal or *intrinsic size effects* are determined as a change of the properties related to particles (the lattice parameters, melting temperature, hardness, band gap, luminescence, diffusion coefficients, chemical activity, sorption, etc.) irrespective of external disturbances.

*External size effects* arise inevitably and always in the processes of interaction between different physical fields and matters under decreasing of their building units (the particles, grains, domains) down to a crucial value, when this size becomes to be comparable with a length of physical phenomena (the free length of electrons, phonons, coherent length, screening length, irradiative wave length, etc.).
What are the possible approaches to making nanomaterials and nanotechnologies?

- There are basically two routes: a **top-down** approach and a **bottom-up** approach.

- The idea behind the **top-down** approach is the following: An operator first designs and controls a macroscale machine shop to produce an exact copy of itself, but smaller in size. Subsequently, this downscaled machine shop will make a replica of itself, but also a few times smaller in size.

- The concept of the **bottom-up** approach is that one starts with atoms or molecules, which build up to form larger structures. In this context, there are three important enabling bottom-up technologies, namely (1) supramolecular and molecular chemistry, (2) scanning probes, and (3) biotechnology.
What is a color of gold?

Size-dependent color of gold

Absorption peak broadens and shifts to longer wavelengths.
Reflection, leading to scattering, is weak at small sizes and increases when > 50 nm.

100 nm gold particles
$\lambda_{\text{abs}} = 575 \text{ nm}$
Color = purple-pink

20 nm gold particles
$\lambda_{\text{abs}} = 521 \text{ nm}$
Color = red

1 nm gold particles
$\lambda_{\text{abs}} = 420 \text{ nm}$
Color = brown-yellow
Who is a master of nano?

NATURE Biology

About 1 nm
The role of the ribosome is to act as a **factory of proteins** by combining amino acids together in a very specific order.

A typical ribosome is located in an aqueous solution surrounded by thousands of solutes.
Bone – nanocomposite?

Fiber bundle
~1 μm

Mineralized fibril
~100 nm

Collagen molecule
~1.5 nm

Mineral particle
~3 nm

Lamella
~5 μm

Trabecular bone

Osteon
~100 μm

Compact bone
Will we live forever?

Injectable Nanobots?

Inspired by Fantastic Voyage, 1966
(General Electric TV Commercial, 2005)

Immortality?

Kurzweil writes of millions of cell-sized robots, which he calls "nanobots," that will keep us forever young by swarming through the body, repairing bones, muscles, arteries and brain cells. Improvements to our genetic coding will be downloaded via the Internet.

HEALTH

Inventor preserves self to witness immortality

WELLESLEY, Massachusetts (AP) -- Ray Kurzweil doesn't tailgate. A man who plans to live forever doesn't take chances with his health on the highway, or anywhere else.

As part of his daily routine, Kurzweil ingests 250 supplements, eight to 10 glasses of alkaline water and 10 cups of green tea. He also periodically rides 40 to 50 miles on a recumbent bike, takes a wild yam supplement to help his "gasline sensitivity," and makes adjustments as needed.

Inventor and author Ray Kurzweil predicts human immortality is no more than 26 years away.
Do we need nano?

Nano = Unnatural Genetics?

Protestors at the Nano Commerce Conference
(Chicago, 2004)
Nanotechnology in the Marketplace
How do the experts view nano pop culture?

Prof. Richard Smalley
Rice University
Nobel Laureate in Chemistry, 1996

*Scientific American* Article:
September, 2001

How soon will we see the nanometer-scale robots envisaged by K. Eric Drexler and other molecular nanotechnologists? The simple answer is never.

National Nanotechnology Initiative:
Second Assessment and Recommendations of National Advisory Panel, April 2008