Nanotechnology

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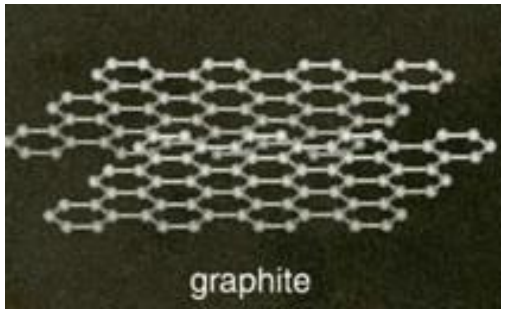
Outline

1. Introduction
2. Nanonotechnology in Agriculture
3. Nanotechnology in Food
4. Nanotechnology, Health and Environmental Concerns
5. Summary

Nanotechnologies

We are the best example of the power of atoms: once they are very well organized, can give surprising behaviors and structures [1]



[1] T. Sargent, 2006.

Nanobiotechnologies

We are the best example of the power of atoms: once they are very well organized, they can give surprising behaviors and structures

What if we can choose a property: for instance to destroy cancerous cells: combining atoms for generating molecules, and the necessary materials to make it possible?

We can remove pollutants from the environment

Our dreams to set the matter according to our needs (or desires) can become a reality?

We analyze better than synthesizing

“The macroscopic reality seems to come mysteriously from the nano(atom)scopic state”

Nanotechnologists goal: to design and fabricate a custom-made material having a precise function

What is Nanotechnology?

So ---

what is this nanotechnology thing anyway?

What is Nanotechnology?

Nanotechnology is the creation of functional materials, devices and systems,

How?

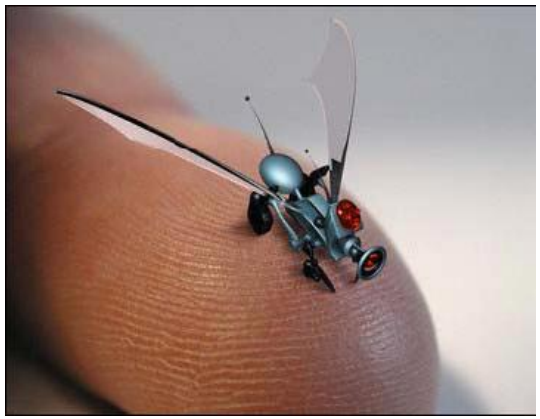
through the understanding and control of matter at dimensions in the nanometer scale length (1-100 nm),

Why?

where new functionalities and properties of matter are observed and harnessed for a broad range of applications

What is Nanotechnology?

Nanotechnology is the science behind the **ability to build anything, atom by atom**, from the ground up



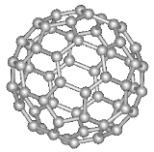
Nanotechnology is **not miniaturization**

What is Nanoscale?

12,756 Km

22 cm

Fullerenes C_{60}



0.7 nm

www.physics.ucr.edu

1.27×10^{7} m → **0.22 m** → **0.7×10^{-9} m**

10 million times smaller

1 billion times smaller

1 nm = 10^{-9} m (1 billionth of 1 meter)

What is Nanoscale?

Laws that govern the **nanoworld** are entirely different from those we are accustomed in **our macroworld**

At the **nanoscale**, the importance of gravity decreases while the importance of Van der Walls forces among atoms or molecules increases

Any change of scale on an object is accompanied by a **radical change of its properties**.

If the size of this object is reduced in a factor of 2, its surface will be reduced in a factor of $2^2 = 4$,

and its volume in a factor of $2^3 = 8$.

What is Nanoscale?

Example: Consider a man 1.80 m height, 80 kg weight. He can lift about 80 kg

- **What if we reduce his height in a factor of 100?**

  So, his new size is going to be 1.8 m /100 = 0.018 m = 18 mm

  His force which is proportional to his muscle surface, will be reduced in a factor of 100^2 = 10,000, thus he will be able to lift a weight of 80 kg/10,000 = 8 g = 8,000 mg

  His weight proportional to his volume, will be reduced in a factor of 100^3 = 1,000,000, thus his new weight will be 80 kg/1,000,000 0,08 g = 80 mg.

  He can lift a weight 100 times his weight!

- **What if we reduce his height to just 18 micrometers?**

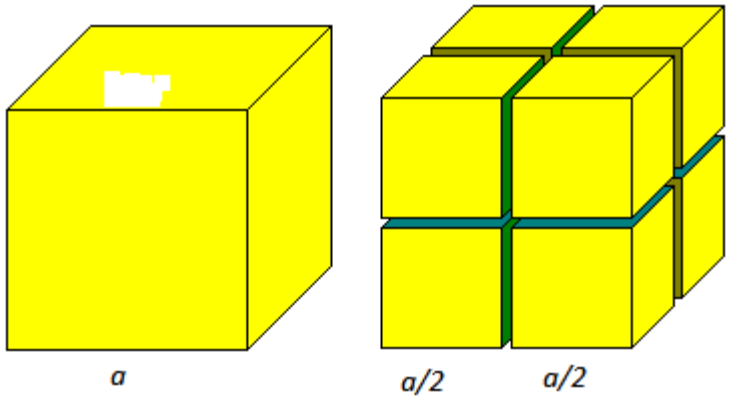
  He will be able to rise 100,000 times his weight

- **What if we reduce his height to just 18 nanometers?**

  He will be able to rise 100 million times his weight!!

Nanoscale Size Effect

Attainment of high surface area to volume ratio

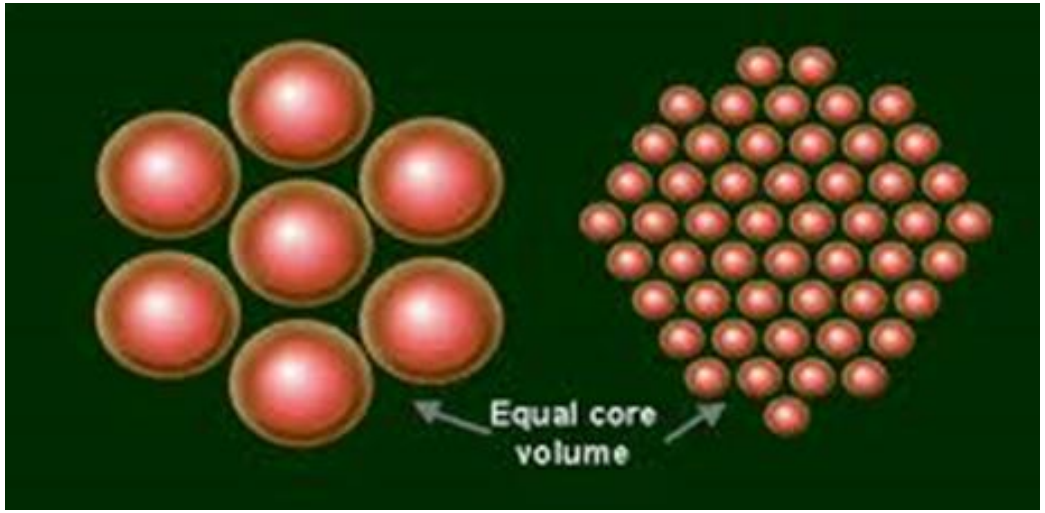


$$SA : V = \frac{6a^2}{a^3} = \frac{6}{a}$$

a (m)	SA/V	V (m^3)
2	3	8
1	6	8
1/2	12	8
$1 . 10^{-9}$	6.10^{+9}	8

Nanoscale Size Effect

Attainment of high surface area to volume ratio



$$SA{:}V = \frac{3}{a}$$

a (diameter)

Nanoscale Size Effect

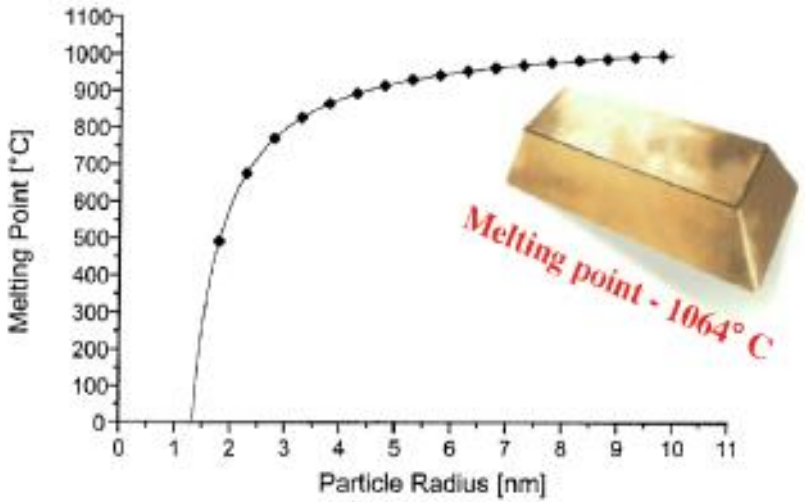
Attainment of high surface area to volume ratio

•Manifestation of novel phenomena and properties, including changes in:

- Physical Properties (e.g. melting point)
- Chemical Properties (e.g. reactivity)
- Electrical Properties (e.g. conductivity)
- Mechanical Properties (e.g. strength)
- Optical Properties (e.g. light emission)

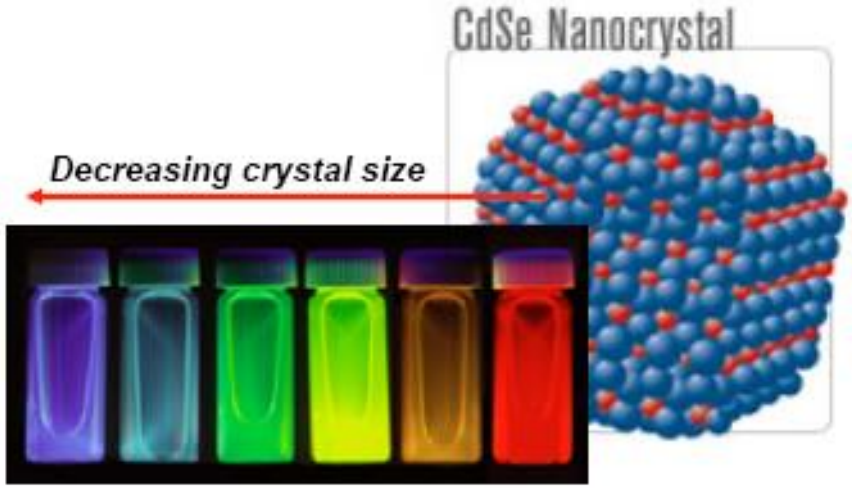
Physical/chemical properties can change as we approach the nano-scale

Melting point of gold particles



K. J. Klabunde, 2001

Fluorescence of semiconductor nanocrystals



M. Bawendi, MIT: web.mit.edu/chemistry/nanocluster
Evident, Inc.: www.evidenttech.com

By controlling nano-scale (1) composition, (2) size, and (3) shape, we can create new materials with new properties → New technologies

Nanotechnology Applications

Information Technology

- Smaller, faster, more energy efficient and powerful computing and other IT-based systems

Medicine

- Cancer treatment
- Bone treatment
- Drug delivery
- Appetite control
- Drug development
- Medical tools
- Diagnostic tests
- Imaging

Energy

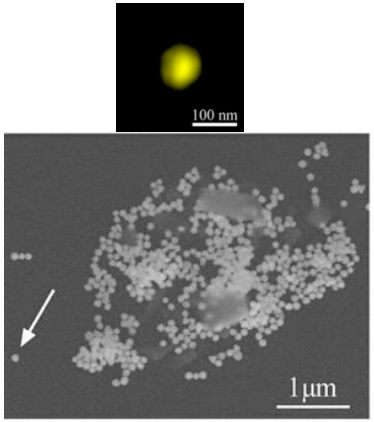
- More efficient and cost effective technologies for energy production
  - Solar cells
  - Fuel cells
  - Batteries
  - Bio fuels

Consumer Goods

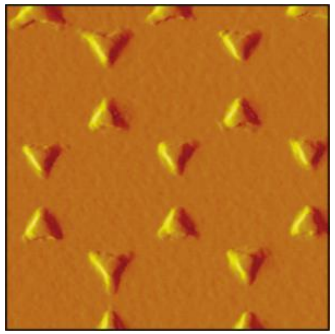
- Foods and beverages
  - Advanced packaging materials, sensors, and lab-on-chips for food quality testing
- Appliances and textiles
  - Stain proof, water proof and wrinkle free textiles
- Household and cosmetics
  - Self-cleaning and scratch free products, paints, and better cosmetics

Nanoscale Materials

Nanoparticles and Structures



Gold nanoparticles for biodetection (i.e. identification of bacteria) and imaging (6-12 nm diam)
– TU Dresden/ESRF, 2008



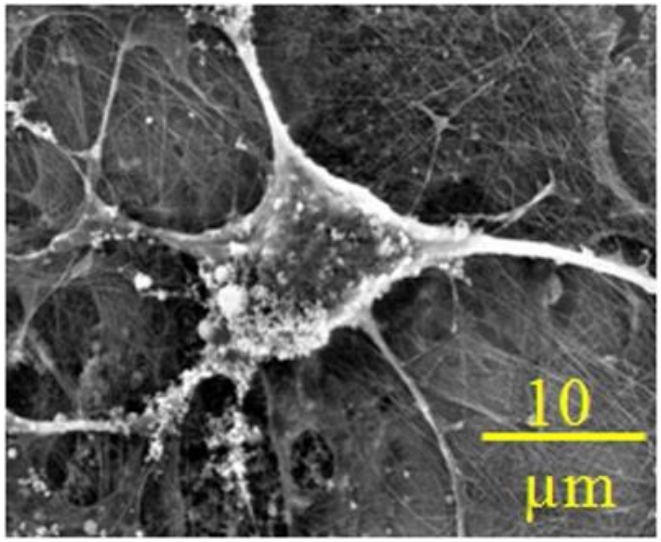
Silver nanoparticles (non-toxic, non-allergic, naturally occurring) (antimicrobial applications) –
Northwestern Univ., 2002

Nanoscale Materials

Bionanomaterials

Synthetic nanomaterials utilized in biomedical applications

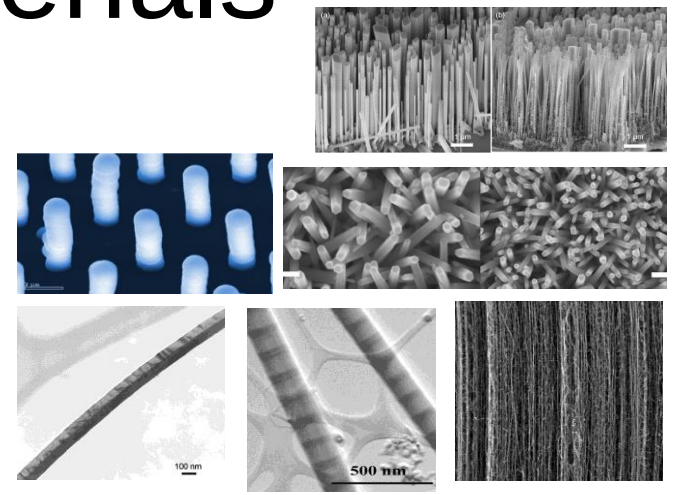
- Polymers, porous silicon



Bone cell on porous silicon

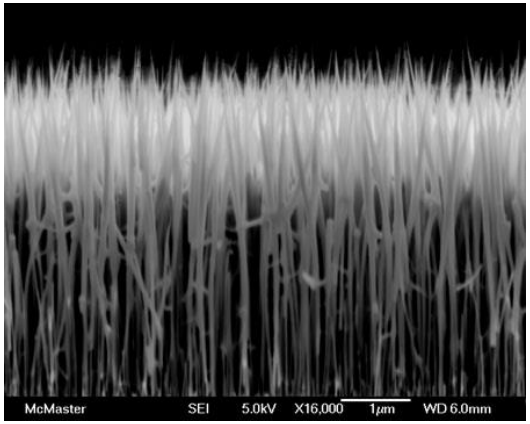
– Univ. of Rochester, 2007

Nanoscale Materials



Nanowires and Nanotubes

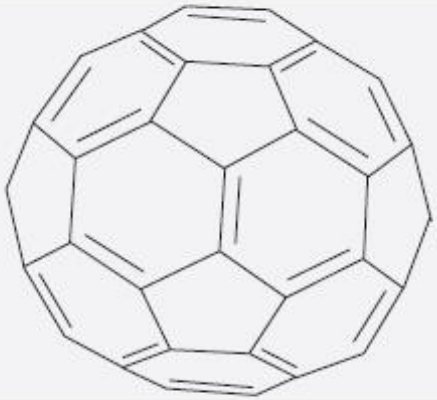
- Lateral dimension: 1 – 100 nm
- Nanowires and nanotubes exhibit novel physical, electronic and optical properties
  - High surface area to volume ratio
- Potential application in wide range of nanodevices and systems
  - Nanoscale sensors
  - Photovoltaic devices – solar cells
  - Transistors, diodes and LASERs



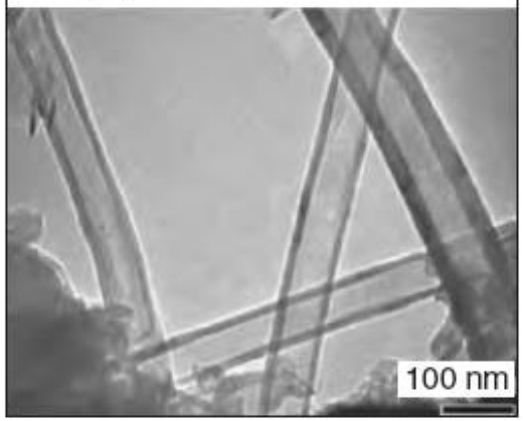
Nanowire Solar Cell: The nanowires create a surface that is able to absorb more sunlight than a flat surface – *McMaster Univ., 2008*

Nanotechnology Materials

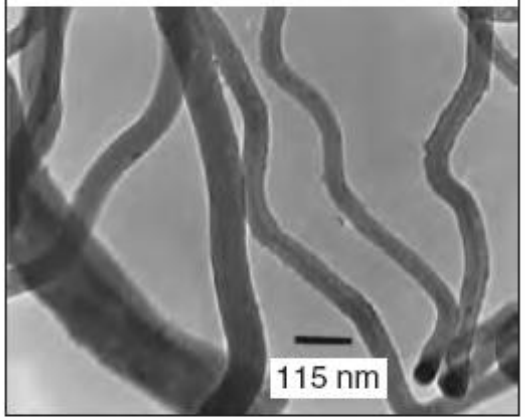
(a) Fullerene C_{60}



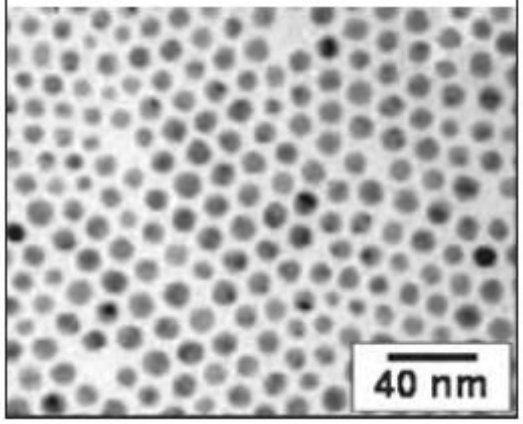
(b) Carbon nanotubes



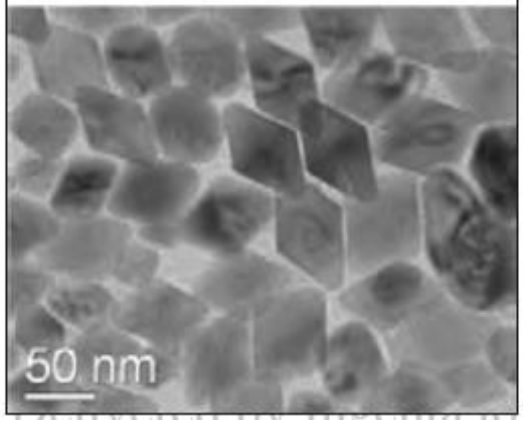
(c) ZnO nanowires



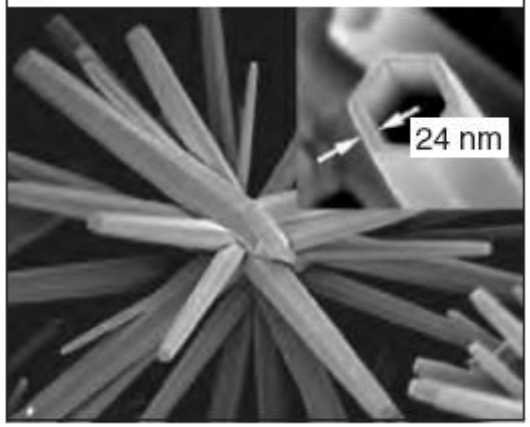
(d) Gold nanoparticles



(e) $LiYF_4$ nanocrystals



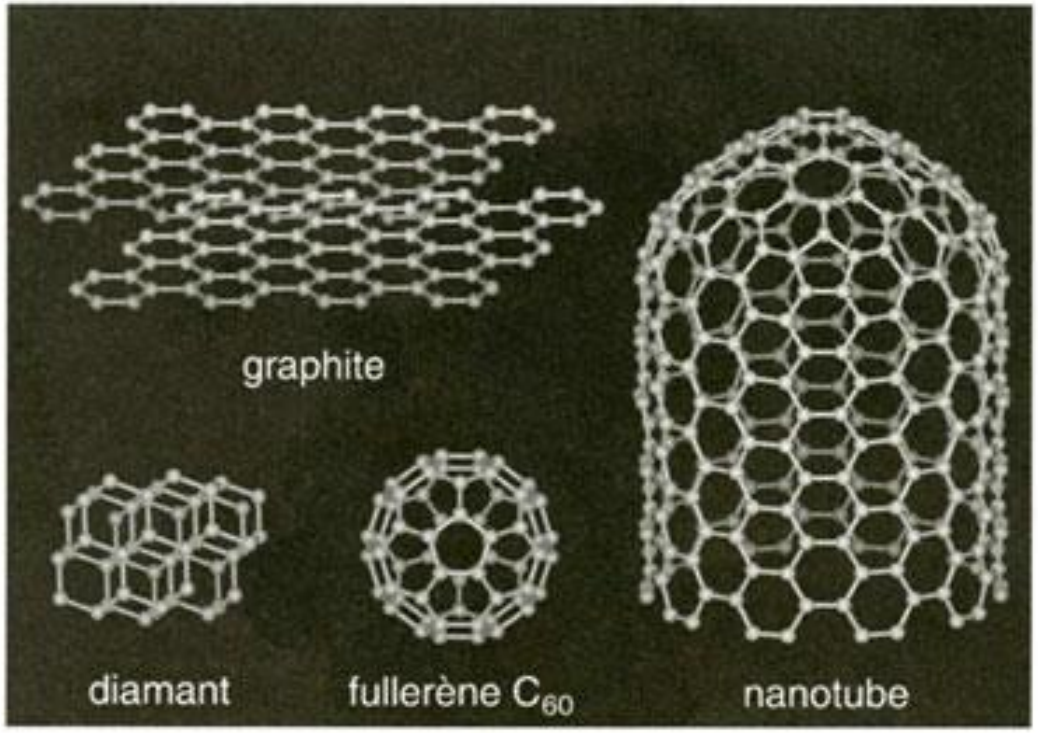
(f) ZnO nanorods & nanotubes



Nanotechnology Materials

Carbon Nanotubes

Carbon nanotubes are composed of carbon atoms bound together into long thin tubes less than 2 nm in diameter



Different structures of carbon atoms (i.e. Coiled up wire nettings) from the discover of fullerenes

Nanotechnology Materials

Carbon Nanotubes

Carbon nanotubes are composed of carbon atoms bound together into long thin tubes less than 2 nm in diameter

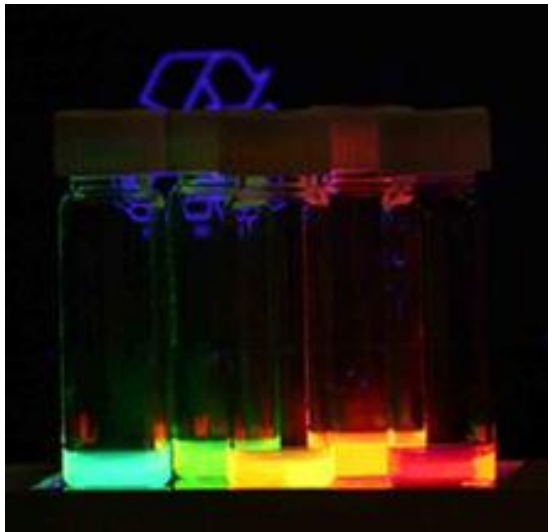
- **Density** of 1.4 grams/cc, compared with aluminum at 2.7 grams/cc;
- **tensile strength** of 45 billion pascals, while **steel alloys** break at 2 billion pascals;
- **ability to carry** 1 billion amps/cm^2, whereas copper wires burn out at 1 million amps/cm^2.
- **applications**: design of semiconductors, chemical and genetic probes, flat-panel displays.

Nanotechnology Materials

Quantum dots

A quantum dot is a **nanosized fluorescent crystal** that emits light after an outside source, such as ultraviolet light (turning from red to blue as its diameter decreases)

They are generally **inert in the body** and consequently are very useful in **tagging proteins and nucleic acids**. When ultraviolet light is shined on a sample, the quantum dots glow, indicating the locations of attached proteins and yielding substantial useful information



Different sized quantum dots emit different color light

Nanotechnology in Food and Agriculture

Why use nano?

• Nanotechnology is transforming the entire food industry: changes in food production, processing, packaging, transport and consumption

• More than 400 companies active in R&D around the world today. 1000 companies the next 10 years

• European Union challenges: Answers to the growing demand for healthy and safe food

Nanotechnology in Agriculture

Why use nano?

• Nanotechnology presents new tools for rapid disease detection and treatment, providing smart sensors and smart delivery systems: enhancing the ability to plants to absorb nutrients, and to combat viruses and crop pathogens

• In the near future nanostructured catalysts will be available to increase the efficiency of pesticides and herbicides, allowing lower doses to be used

Nanotechnology in Agriculture

Why use nano?

• Precision farming: maximize outputs (i.e. crop yields) while minimizing inputs (fertilizers, pesticides, herbicides); through monitoring of environmental variables and through targeted actions [2]

• Deliver chemicals (pesticides, herbicides dissolved in water or nanoemulsions)) in a targeted way through encapsulation, to control their release

• Smart agricultural systems: computers, GPS, and remote sensing devices

[2] Luvall et al., 2010

Nanotechnology in Agriculture

- Smart wireless sensors are linked to GPS and allow real time monitoring for early warning system

Sensors are based on the use of carbon nanotubes or nanocantilivers small enough to trap protein or small molecules, providing an electrical or chemical signal

Nanotechnology in Agriculture

Some applications

- Plant grow regulator (Primo MAXX, Syngenta). To deliver chemicals in a controlled and targeted way: by encapsulation, based on the use of nanoemulsions of pesticides (applied on turfgrass)

- Aluminium oxide nanofibers (NanoCeram). For water purification (filters). Filters remove viruses, bacteria from water.

Nanotechnology in Agriculture

- Lanthanum nanoparticles can absorb phosphate from water (ponds, and swimming pools)

- Nanoscale iron powders can be used for cleaning soil and groundwaters. Iron can oxidize TCE, CCl_4, dioxins and PCBs

- Insecticide "Gutbuster" (Syngenta). Encapsulated product that breaks down in alkaline environments: the stomach of certain insects [3]

[3] Syngenta's US Patent No. 6,544,540

Nanotechnology in Food

Why use nano?

• Applications: Smart packaging, on demand preservatives and interactive foods

• Interactive foods: to allow consumers to modify food depending on their own nutritional needs, allergies or tastes: nanocapsules (containing flavor, color enhancers, vitamins) remain dormant in the food and release when triggered by the consumer

• Smart packaging to increase food shelf life by detecting spoilage, bacteria, or the loss of nutrients

Nanotechnology in Food

- **Smart nanocapsules** that can be incorporated into food to deliver nutrients, i.e. nanocapsules containing tuna fish oil (omega 3 fatty acids). Capsules break down only in the stomach

- Addition of nanoparticles to existing foods to enhance absorption on nutrients

Nanotechnology in Food

Nano is already in food, but where?

- Manufactured nanomaterials are already used in some food products, nutritional supplements, many packaging and food storage applications and some agricultural inputs (e.g. fertilizers and pesticides)

where's the nano? = lack of labeling laws + secrecy in commercial use

Nanotechnology in Food

Some applications of nanoparticles in food

- **Nutritional drink:** nano iron drink for toddlers offers increased bioavailability (Toddler Health)

- **Food contact material:** nano silver baby mug with increased antibacterial properties (Baby Dream)

Nanotechnology in Food

Food quality

Attractive surface (packaging), glaze and colors

Improvement of food flavor, smell…

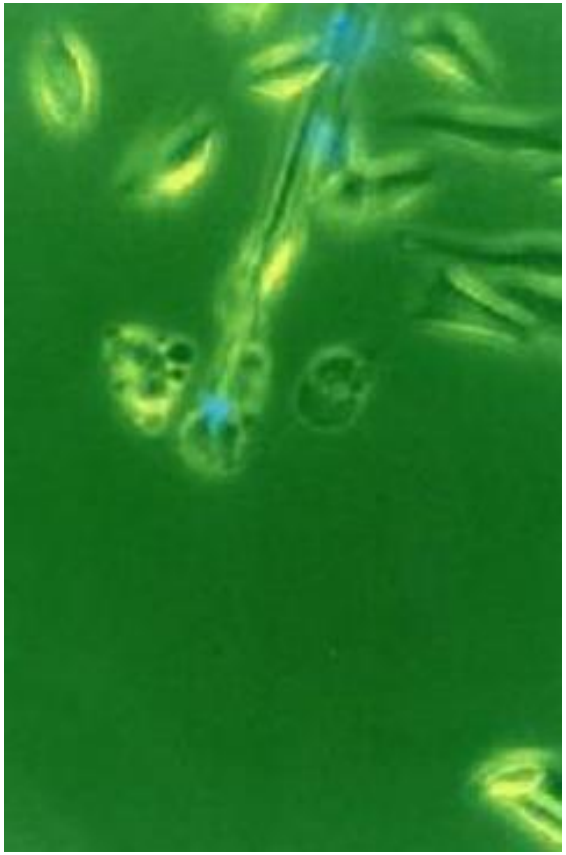
Extension of product shelf-life

Nanotechnology in Food

Detection of pathogens by nano(biosensors)

Nanocantilivers

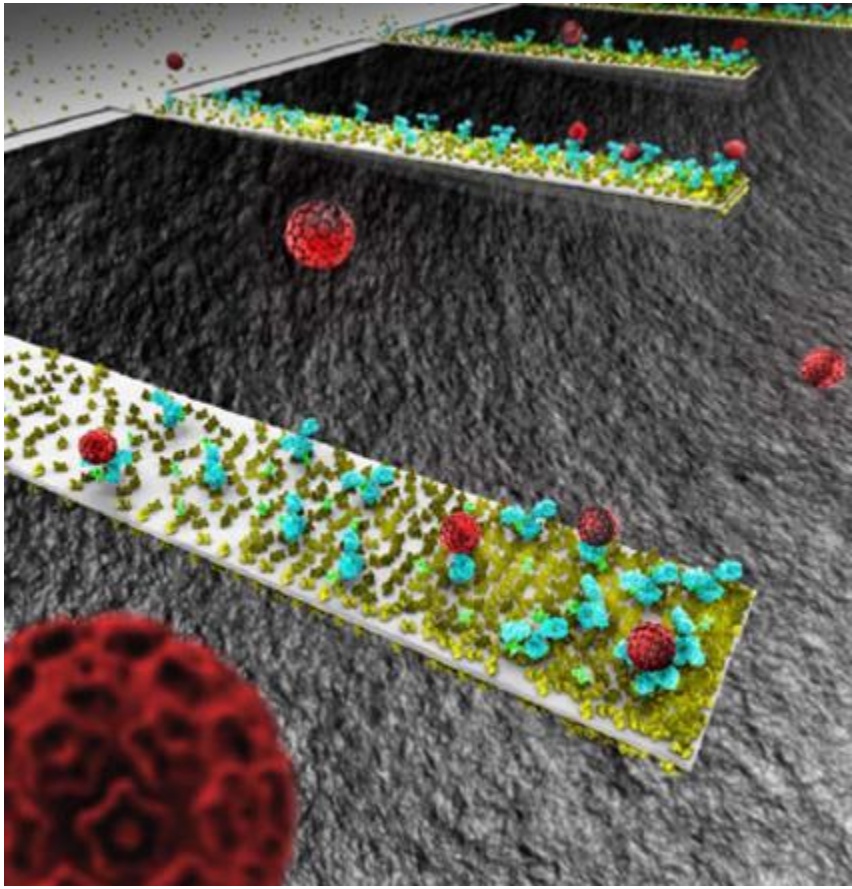
Nanowires



Nanotechnology in Food

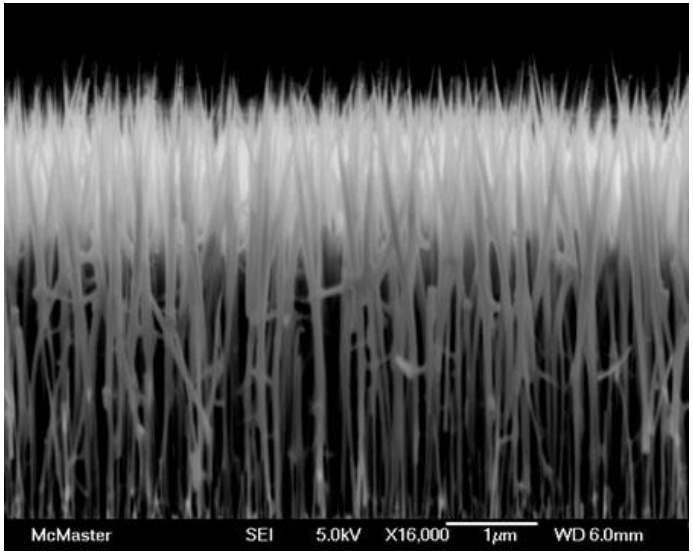
Nanocantilevers

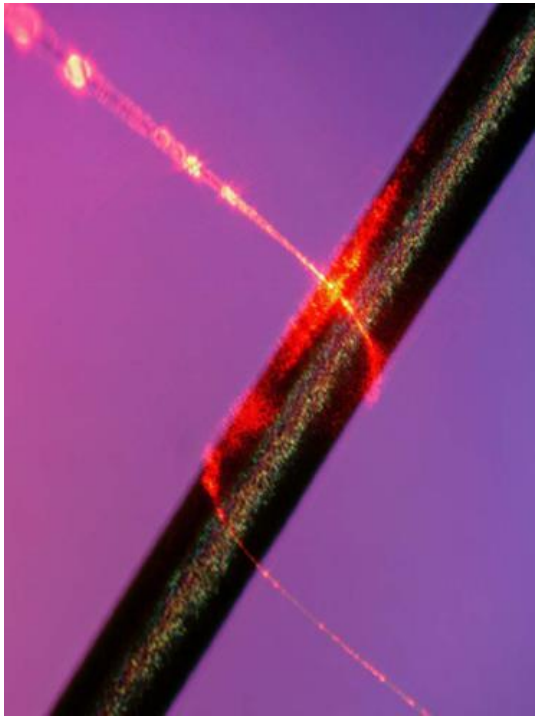
Looks like tiny diving boards made of silicon that vibrate at different frequencies when contaminants stick to them, revealing the presence of dangerous viruses and bacteria



Nanotechnology in Food

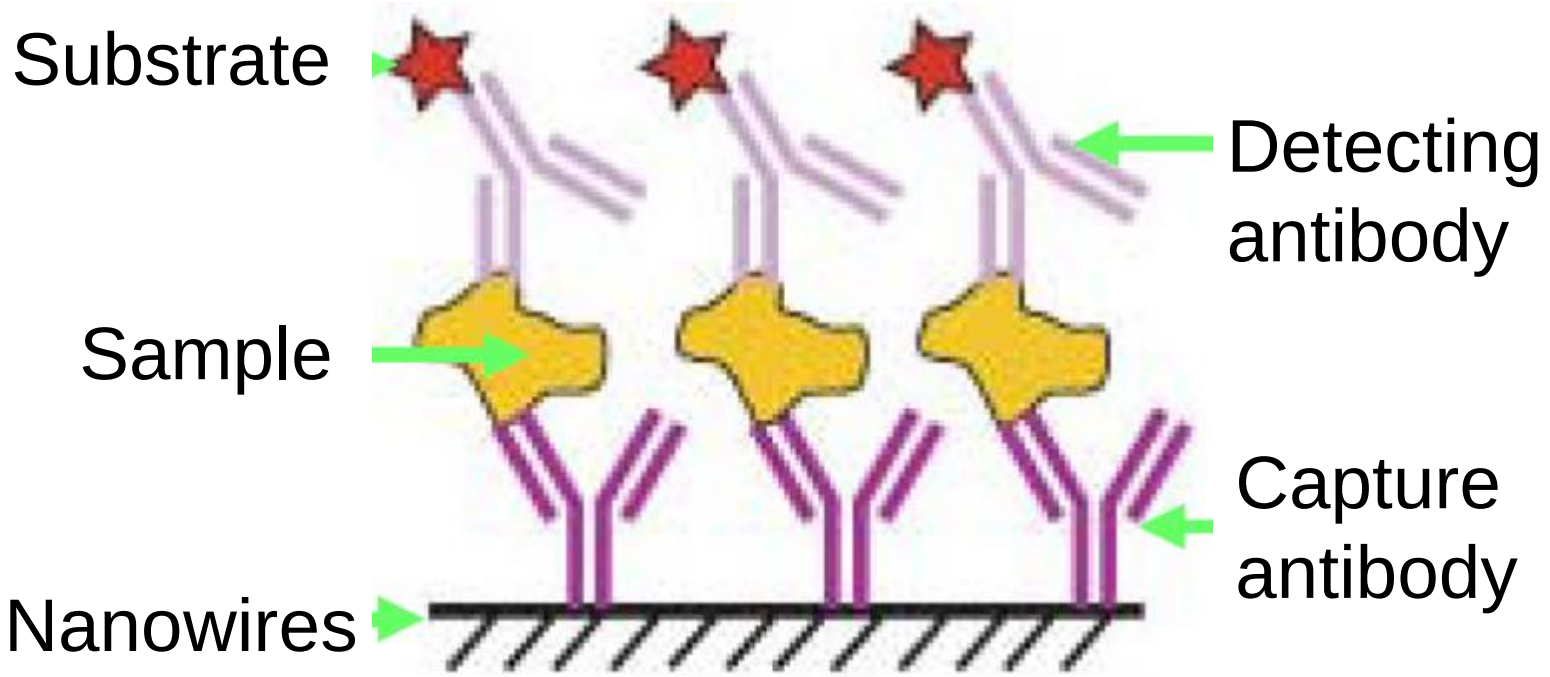
Nanocantilevers





Nanotechnology in Food

Sandwich Immunoassay



Nanotechnology in Food

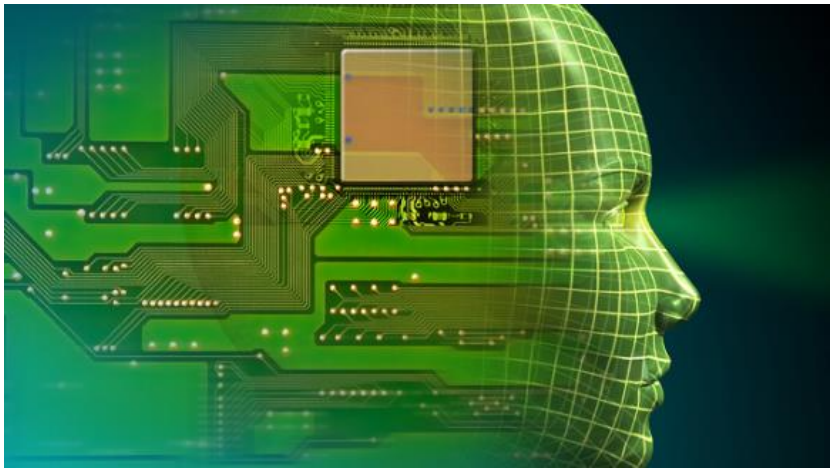
Pathogen Detection

Nanobioluminescence Detection spray:
A luminescent protein that binds the Salmonella *E. Coli*, emitting a visible glow

Nanotechnology in Food

Nanosensor: Electronic tongue

Array of nanosensors sensitive to gases released by food as it spoils: Useful to detect non-fresh food



Nanotechnology in Food

Nanosensor: General uses

Detect/retards spoilage & bacterial growth
Monitoring of time/ T°/moisture

Nanotechnology in Food

Nanocomposites

Plastic + clay nanoparticles

- Increased shelf life (retards spoilage)
- Better at sealing in CO_2
- Barrier to O_2

Nanotechnology in Food

Intelligent packaging

Milk cartons that change color as milk goes bad

Silver nanoparticles reduce bacteria by 99.9%

Nanotechnology in Food

Nanocomposite

Plastic wrapping. Silica nanoparticles (lighter, stronger, heat resistant

Prevents contents from drying out
Protection against moisture and O_2

Prevents contents from drying out. Protection against moisture and

Nanotechnology in Food

Food contact material

Nano silver cutting board

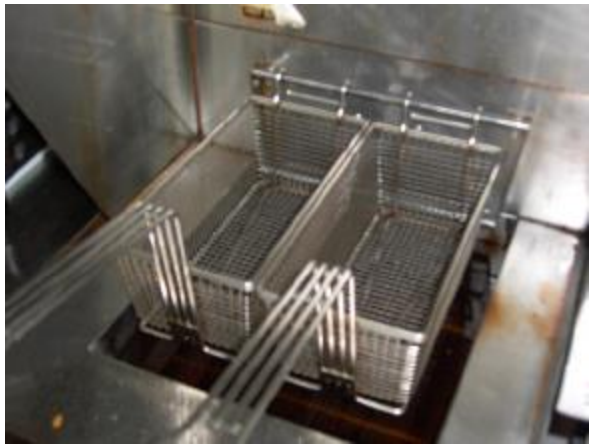
Silver nanoparticles increasing antibacterial properties

The plastic film is lighter, stronger and heat resistant

Prevents contents from drying out. Protection against moisture and O_2

Nanotechnology in Food Processing

Nanoceramics to reduce oil use by half in fat fryers



Preventing oxidation and agglomeration of fats (increased surface area)

Environmental Risks from nanotechnology in food and agriculture

– Antibacterial nano food packaging and nano-sensor technologies may interfere with beneficial bacteria in our bodies and the environment, and result in the development of more virulent harmful bacteria (Melhus 2007; Senjen 2007; Throback et al. 2007)

– Highly potent antibacterial nanomaterials could disrupt the functioning of beneficial bacteria in the wider environment, example in nitrification and denitrification in freshwater and the marine environment (Throback et al. 2007)

Summary

- Nanotechnology is here - to stay
- Application in food products and food safety will continue to grow
- Little data on health & safety issues

Nanotechnology websites:

- Nanotechnology World
- Science news magazine
- Phys.org

A book:

Ted Sargent. 2006. The DANCE of MOLECULES. How Nanotechnology is changing our lives. Thunder's Mouth Press, New York

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Integrating Food Science and Engineering Knowledge Into the Food Chain

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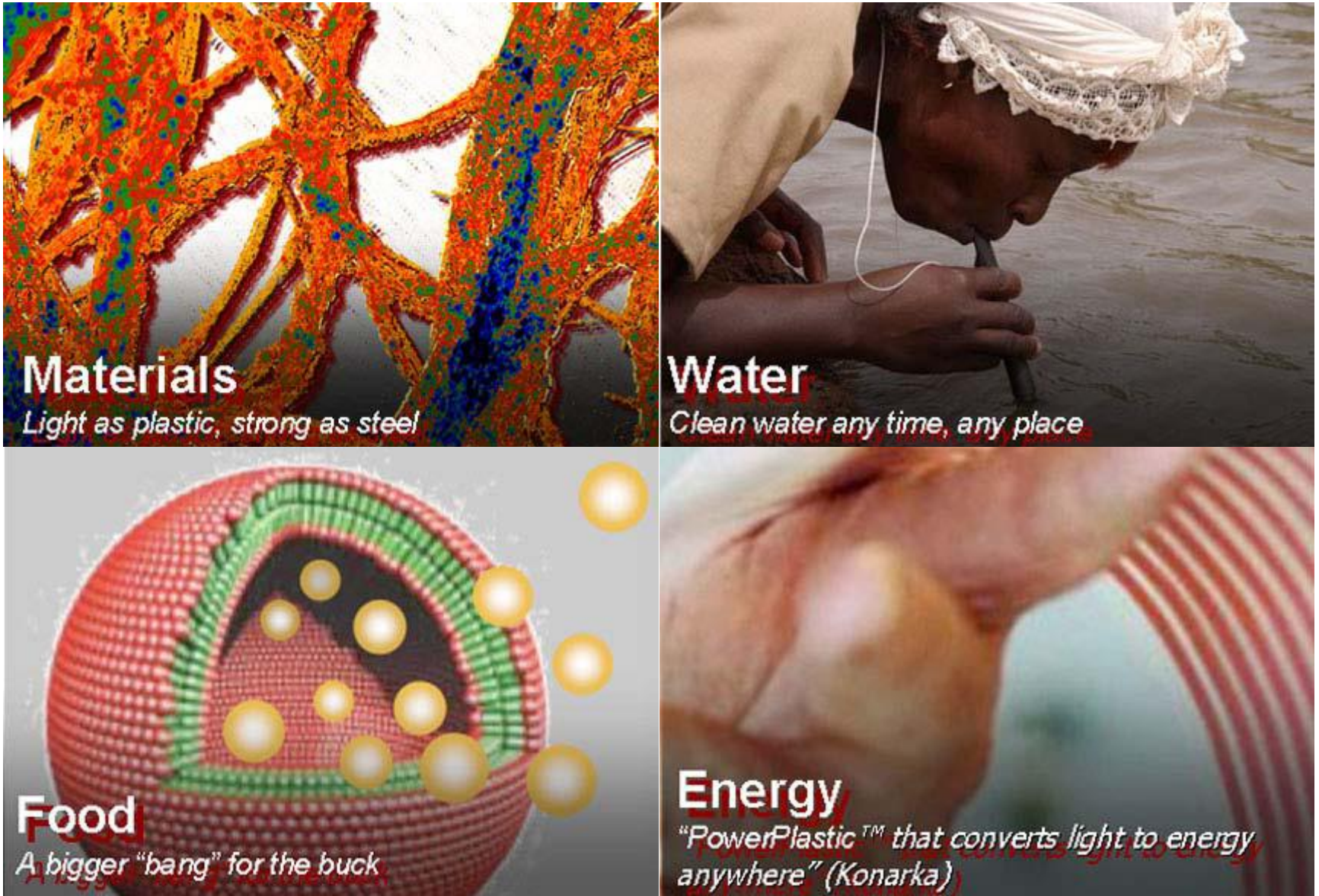
- DI Dr. Helmut Glattes
- Dr. Velitchka Gotcheva
- Direction of the LaSalle Beauvais

Nanotechnology: The Promise



Nanotechnology Health and Environmental Concerns

Nanotechnologies are very promising, but presents some concerns!!

Nanotechnology Health and Environmental Concerns

Nanotechnology Health and Environmental Concerns

Environnement

Les nanotechnologies en débat

NOS TUBES de crème solaire en contiennent, notre voiture en est truffée, tout comme notre mobilier ou notre électroménager… Plus de 800 produits de notre vie courante contiennent des nanomatériaux. Ces particules miniatures, 50 000 fois plus fines que l'épaisseur d'un cheveu, sont utilisées pour leurs propriétés antibactériennes, leur résistance ou leur imperméabilité par les fabricants de textile, l'industrie cosmétique et pharmaceutique.

Parce qu'elles sont une promesse d'avenir en matière médicale et industrielle mais aussi une source d'inquiétude pour notre santé, le ministre de l'Ecologie, Jean-Louis Borloo, lance aujourd'hui un grand débat national sur ce sujet sensible — les nanotechnologies et leur régulation — avec l'organisation de réunions ouvertes à tous, un peu partout en France.

On y apprendra par exemple que les nanoparticules offrent déjà une meilleure durée de vie aux pneus et permettent au béton de sécher trois fois plus vite. Mais certains médecins s'inquiètent du développement de ces microfibres qui, une fois libérées dans l'air et inhalées, pourraient se retrouver dans notre sang et peut-être déstabiliser le fonctionnement de nos cellules.

FRÉDÉRIC MOUCHON

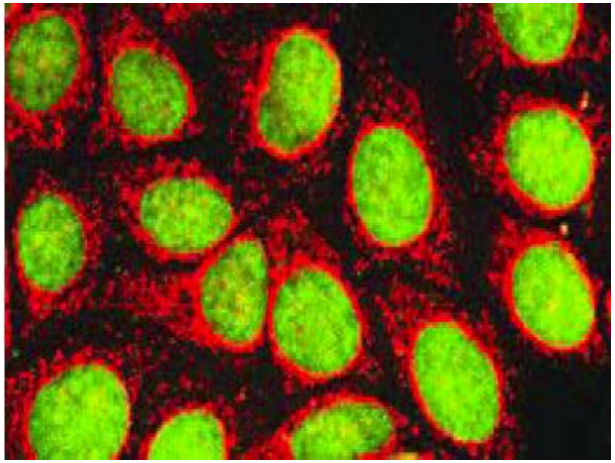
"Le Parisien", 23 Sep 2009

Nanotechnology Health and Environmental Concerns

- **Naturally occurring "ultrafine particles"**
  - *Virus – 10 nm to 60 nm*
  - *Bacteria – 30 nm to 10 μm*
  - *Dust from deserts - ~100 nm*
  - *Volcanic ash, Forest fire smoke*
- **"Ultrafine particles" from established technologies or by-products of conventional processes**
  - *Combustion soot – 10 nm to 80 nm*
  - *Paint pigments – 80 nm to 100 nm*
  - *Welding fumes – 10 nm to 50 nm*
  - *Diesel exhaust particles – (small mode) 7 nm to 40 nm*
  - *Carbon black for photocopier toner – 10 nm to 400 nm*
- **Engineered nanoscale materials – "nanomaterials"**
  - *Fullerenes - buckyballs – 1 nm; nanotubes – 1 nm to 5 nm X 10 μm*
  - *Quantum dots – 5 nm to 20 nm*
  - *Semiconductor wires*

Nanotechnology Materials

What are potential harmful effects of nanoparticles?



Red- and green-emitting quantum dots are used to highlight the mitochondria and nuclei, of human epithelial cells in culture. Although these colorful nanocrystals don't seem to harm the cells, could they pose unforeseen hazards to people or the environment?

Silica-coated semiconductor nanocrystals are easily incorporated into a wide variety of eukaryotic cells.

In experiments where the quantum dots are deposited on a collagen substrate and then cells are deposited on top of this, the cells incorporate any quantum dots that underlie them

When the cells migrate on a substrate, they ingest all the dots they pass over providing a convenient and rapid way for assessing the cells' potential to metastasize, or spread (as a cancer) from one part of the body to another [Adv. Mater., 14, 882 (2002)].

The dots appear to go into cells as "inert spectators." The cells remain healthy and even continue to divide, with each cell division reducing the number of dots in any given cell.

The dots have no discernible effect on the cells.

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