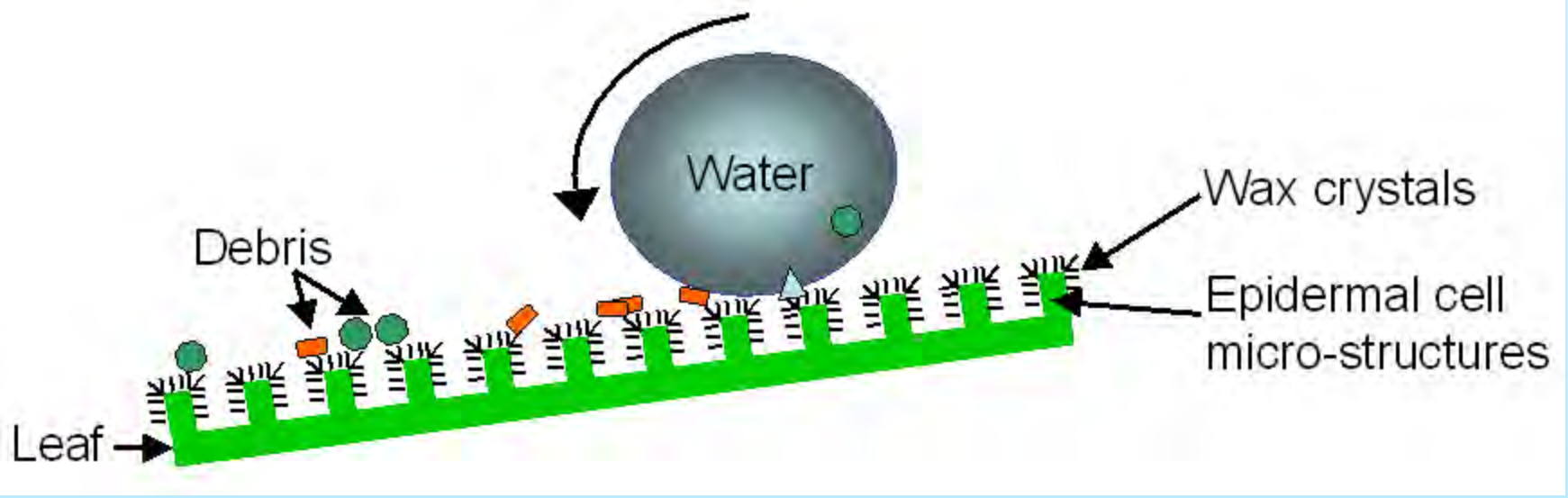
Advances in Nanoscience and Nanotechnology

Sabu Thomas
International and Interuniversity Center for Nanoscience and Nanotechnology,School of Chemical Sciences
Mahatma Gandhi University
Kottayam, Kerala,India
www.iiucnn.com,www.sabuthoms.com

What is Nanotechnology?

WHAT DOES NANOTECHNOLOGY

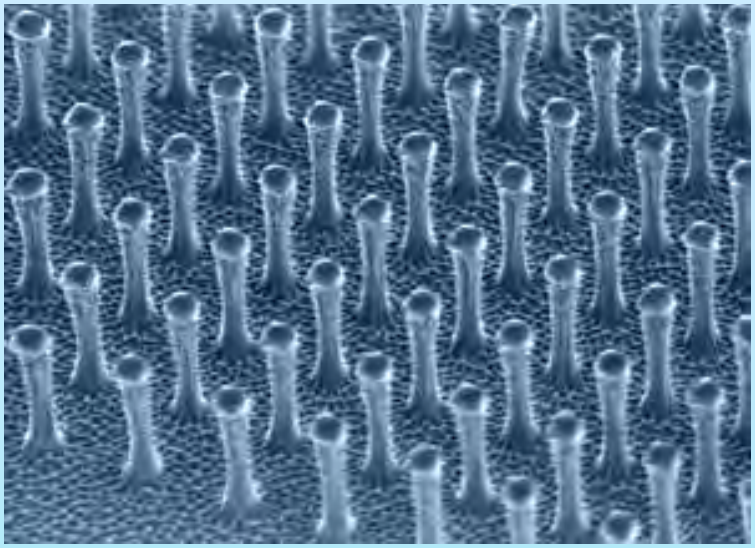
MEAN TO YOU?



The Lotus Effect. Water forms droplets on the tips of the epidermal
protrusions and collects pollutants, dirt and small insects as it rolls off the leaf

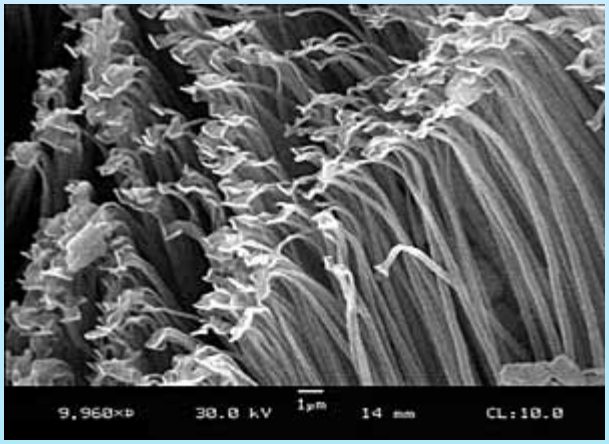
modifies glass surfaces into super-hydrophobic that means that raindrops fall away leaving windscreen dry

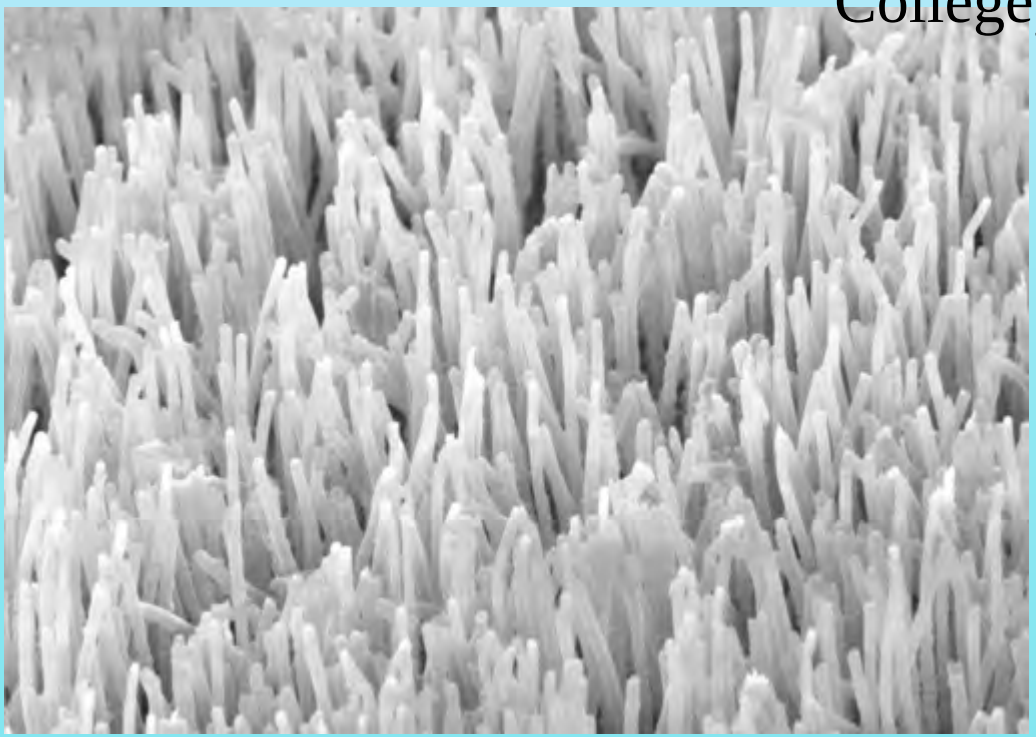
NANO-WIPE -
Invisible Wiper



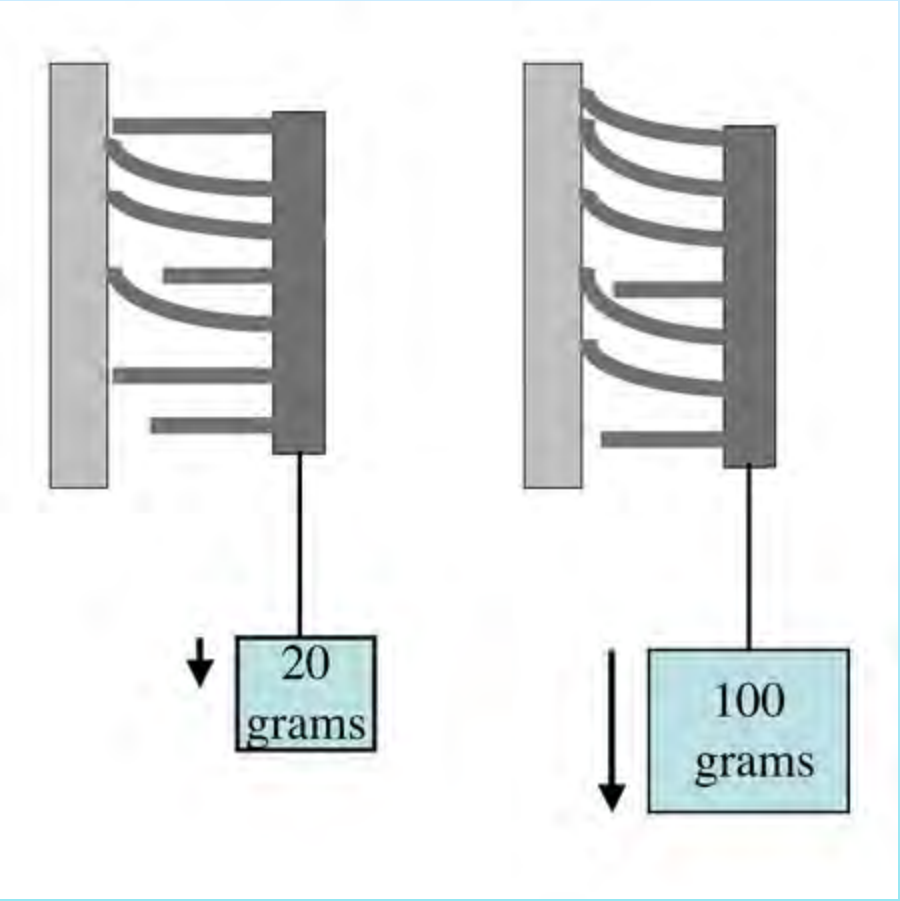
Scanning electron microscope image of a 1cm^2 section of the G

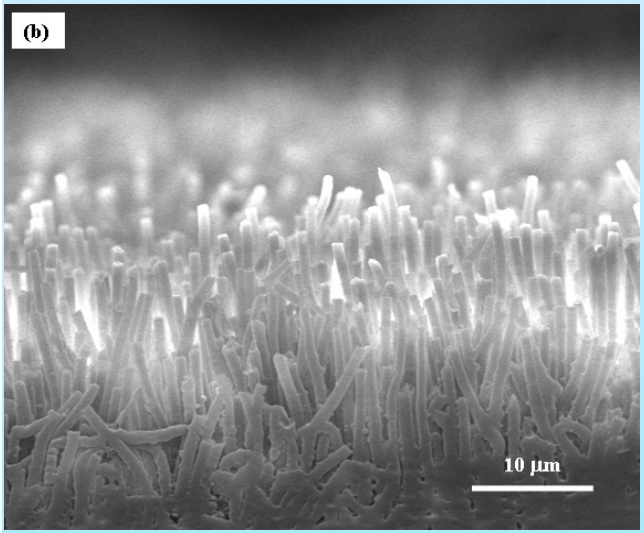
"Spider-Man test" of gecko



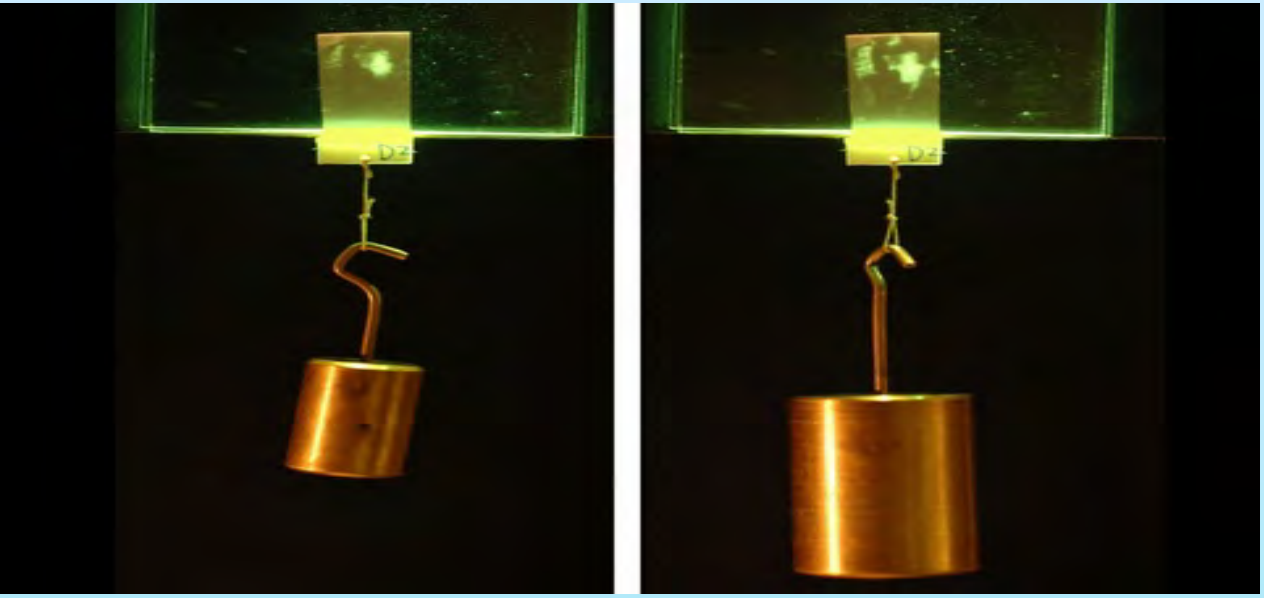


A pair of scanning electron micrographs show similarities between synthetic polymer fibers created by UC Berkeley researchers (below) and the setae from an Anolis lizard. (Photo above of Kellar Autumn, Lewis & Clark College)





Side view of polypropylene microfibers. Each fiber is 15-20 micrometer long, and 0.6 micrometer in diameter. Conceptual drawing showing how more microfibers contact glass when load increases.



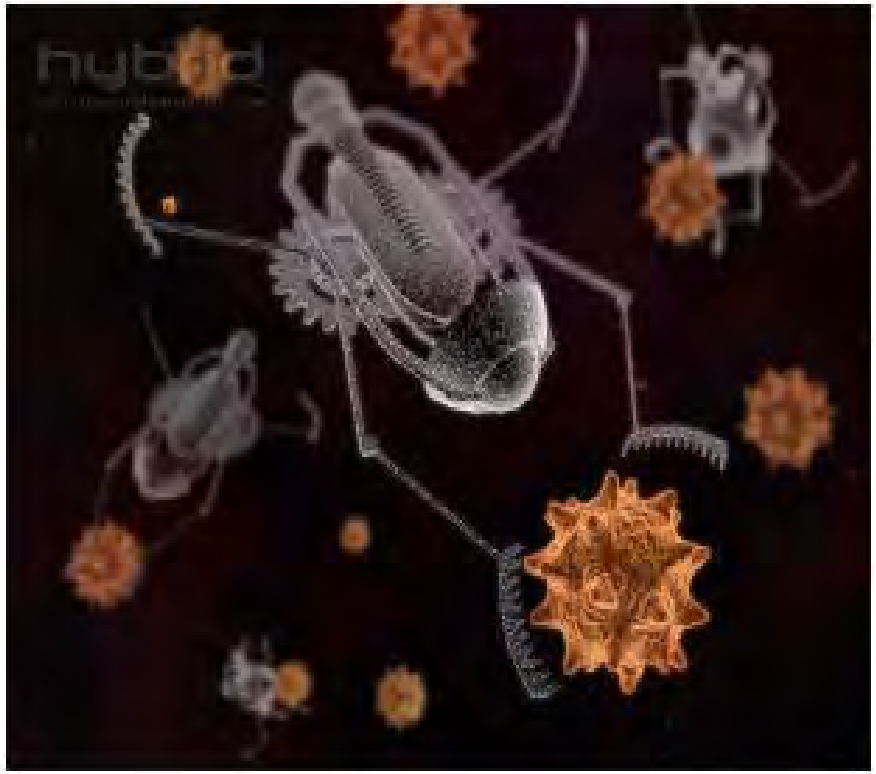
Gecko-inspired adhesive supporting weight. Increasing weight increases contact area. Contact area is bright area near top of patch.
Adhesive is ``smart'' in that greater load causes more microfibers to engage, increasing adhesion strength. Decreasing load allows fibers to disconnect, making release easy.

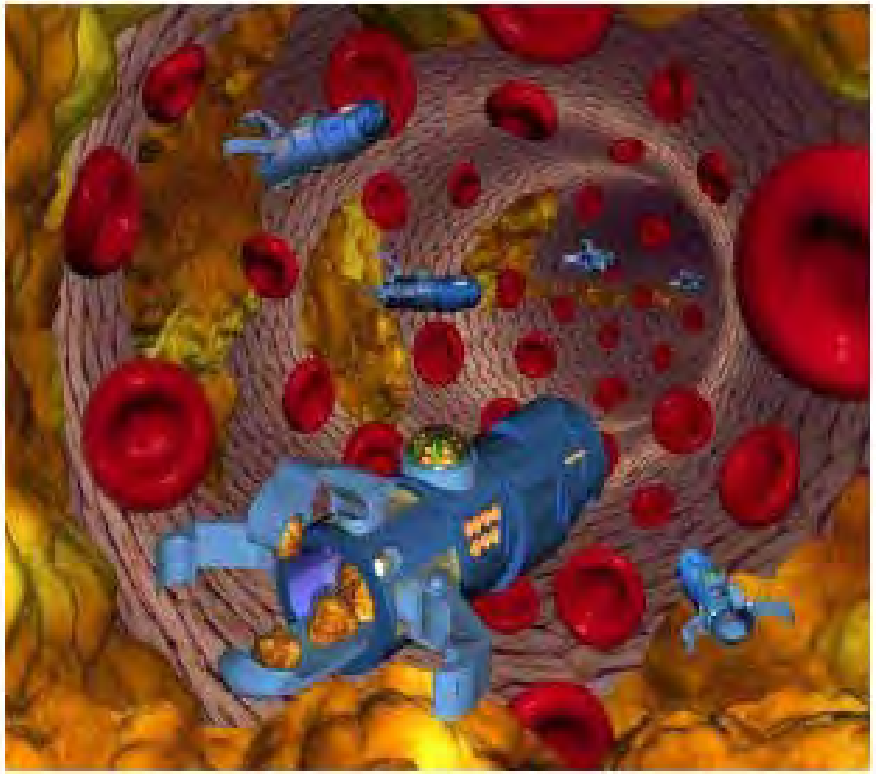
What is Nanotechnology?

Tiny machines in your body curing cancer?

Scientists at the University of California-Los Angeles (UCLA) work on 'nanomachines' to treat cancer. The mechanised nanoparticles include tiny valves and impellers to help release chemotherapy drugs exactly where they are

Injectable Nanobots?





A new breed of nanobots is being designed to assist doctors by going where no surgeon or technology has gone before (could bring about a new type of molecular surgery). Can deliver drugs to areas such as the eyeball cavity or arteries in the heart.

History

How long have nanoparticles been used?
Months?.... Years?..... Centuries?.....

- Pottery using nano-sized particles has been in use for thousands of years
- The chalice, is not a unique example of nanoparticles being used in centuries past; pottery from the 9th century AD from the Mesopotamian era also contains nanoparticles in glazed films applied to ceramic pottery.

Is Nanotechnology really new?

- *And he [Moses] took the [golden] calf they had made and burned it in the fire; then he ground it to powder, scattered it on the water and made the Israelites drink it." Exodus 32:20*

- Gold nanoparticle can be suspended in water to make a colloidal gold, used for centuries as a medical treatment that reportedly *cleared the mind, increased intelligence and will power, and balanced the emotions*.

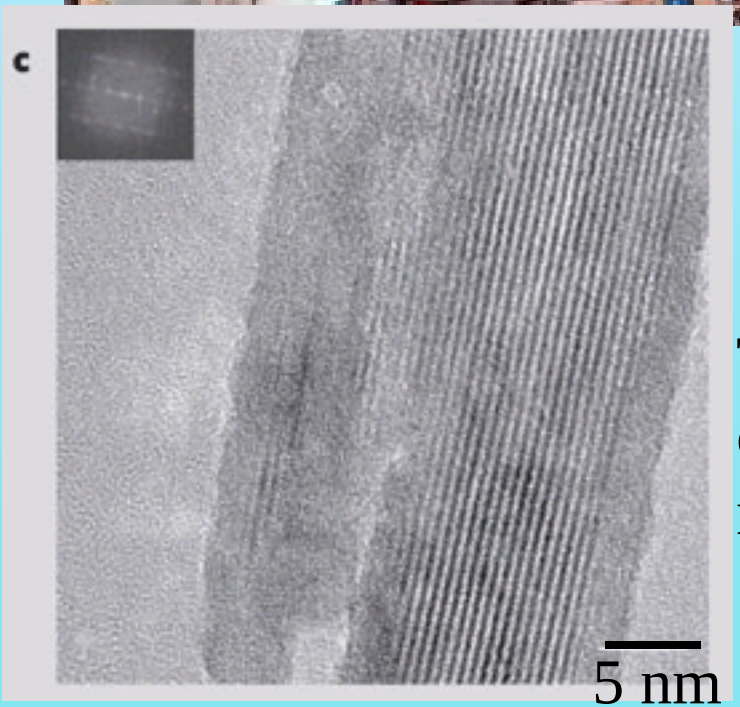
- Is Moses Father of Nanotechnology?

Nano in the Middle ages

Plasmon resonances give to specific metallic nanoparticles a strong and well defined color. This effect was already used in the Middle Ages to fabricate stained-glass windows.

Is Nanotechnology really new?

During the middle ages, the Muslims who fought crusaders with swords of Damascus steel had a high-tech edge - carbon nanotubes and nanowires in their sabres. Damascus sabres were forged from Indian steel called *wootz*. It is likely that the sophisticated process of forging and annealing the steel formed the nanotubes and the nanowires, and could explain the amazing mechanical properties of the swords .



TEM image of cementite nanowires

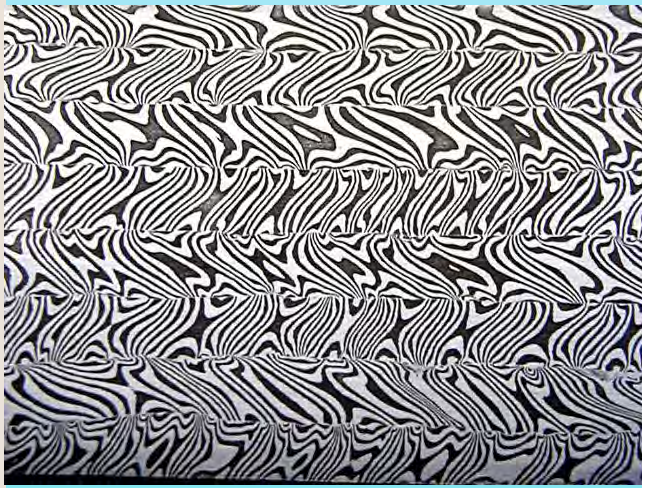
NATUREl. 444, p 286

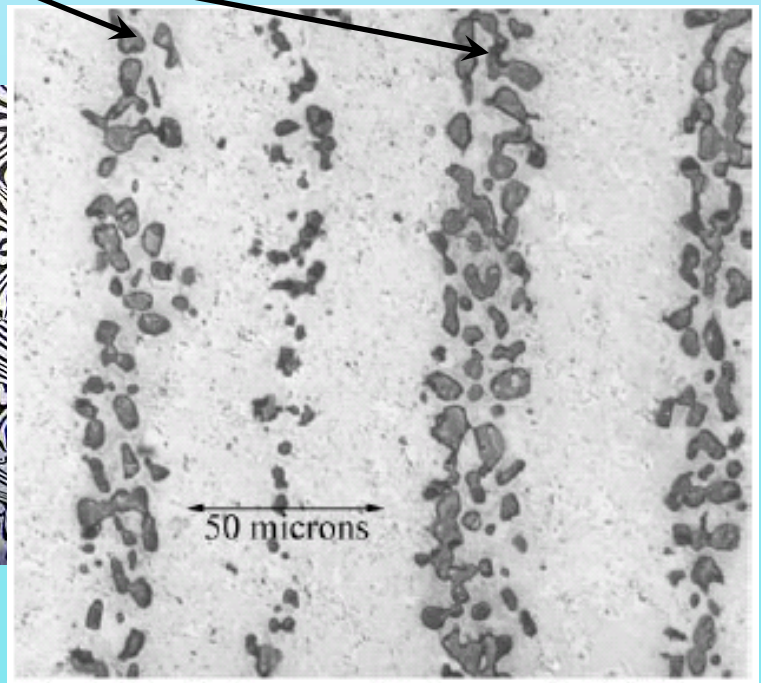
Damascus Steel

Damascus blade showing the Damascene surface pattern containing a combined Mohammed ladder and rose pattern

Such blades were reputed to be tough, resistant to shattering and capable of being honed to a sharp, resilient edge.

Cementite bands





Lycurgus chalice –oldest known object which used nanosized particles

This unusual optical effect is caused by **70nm** particles of silver and gold contained within the glass. (The glass contains 40 parts per million of gold and 300 parts per million of silver, and the particles consisting of seven parts silver to three parts gold.)

It is possible that, while the glass was being made, some scrap metal and slag containing silver and gold was added, and the unusual effect was achieved by accident. The understanding that glass could be coloured red by adding small amounts of gold is often credited to Johann Kunckel, who worked in Germany in the late seventeenth century.

Is Nanotechnology really new?

•Lycurgus cup,4th century AD (now at the British Museum, London).

• Depicts King Lycurgus of Thrace being dragged to the underworld

• When illuminated from outside, it appears green. However, when illuminated from within the cup, it glows red.

Is Nanotechnology really new?

- Lycurgus cup,4th century AD (now at the British Museum,London).The colors originates from metal nanoparticles embedded in the glass. At places, where light is transmitted through the glass it appears red, at places where light is scattered near the surface, the scattered light appears greenish.

Suspensions of spherical gold particles with various diameters (150, 100, 80, 60, 40, 20 nm from left to right) in water. The difference in colors is due to different scattering and absorption behaviour of small and large gold particles.

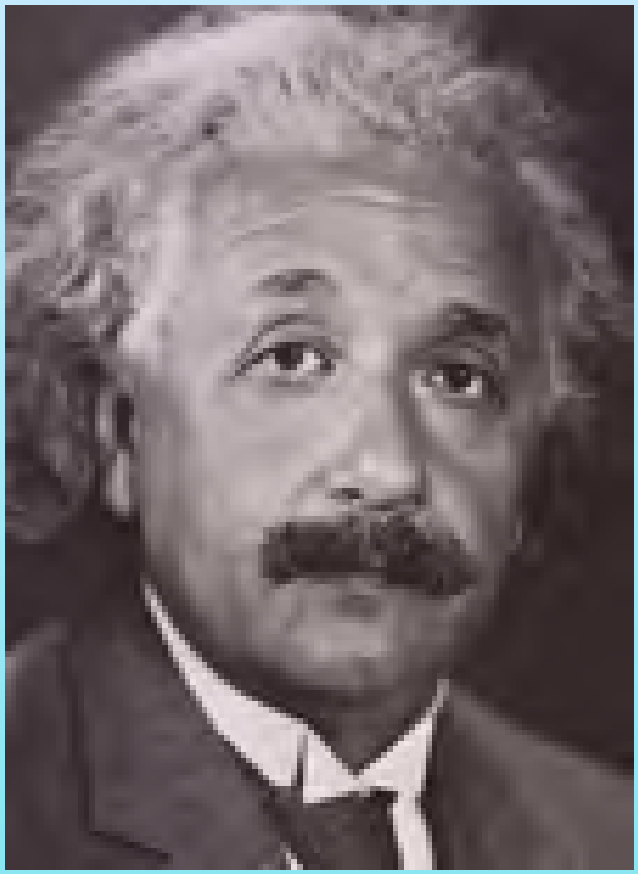
Nanotechnology Milestone

•Michael Faraday discovers colloid gold in 1857

•Michael Faraday introduced ‘ colloidal gold’ samples to the Royal Society. This suspension of gold nanoparticles in solution was totally transparent in some lighting, but in other lighting conditions could produce differently coloured solutions of ‘ruby, green, violet or blue’.

Philosophical transactions of the Royal Society, 1857, 147,

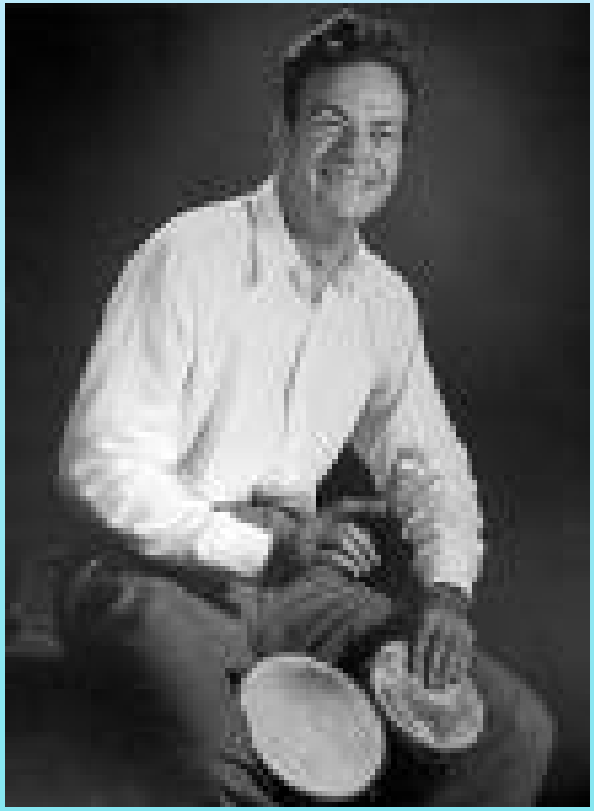
Nanotechnology Milestone



- Albert Einstein provided a thoroughly quantitative theory for the state of a colloid dispersion. He considered colloids to behave as ‘big atoms’ and explained their movement in terms of Brownian motion. [1905]

Nanoscale possibilities- First vision [1958]

Feynman suggests that there is '**plenty of room'** to work at the nanoscale



•Richard P. Feynman gave a ground-breaking speech 'There's plenty of room at the bottom' where he discussed the possibility of controlling materials at the level of atoms and molecules – this was the first vision of the possibilities of science and technology at the nanoscale. He became a Nobel laureate in 1965

Nanotechnology Milestone….

Term ‘Nanotechnology’

- The term ‘nanotechnology’ was coined in 1974 by Norio Taniguchi of the University of Tokyo. He used the word to refer to ‘production technology to get the extra high accuracy and ultra fine dimensions, i.e. the preciseness and fineness on the order of 1 nm (nanometre)’

Nanotechnology Milestone….

Invention of STM [1981]

IBM invent a machine which can move single atoms around

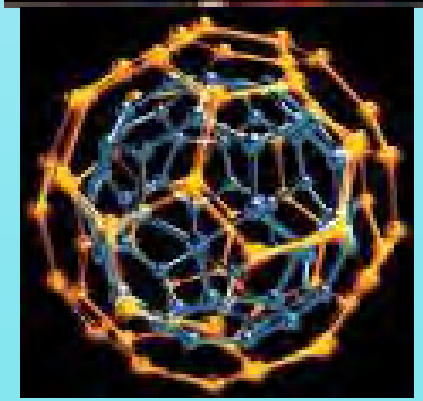
•Gerd Binning and Heinrich Rohrer invented the Scanning Tunneling Microscope (STM) at IBM.

This microscope allows atomic-scale three-dimensional profiles of surfaces to be obtained. The microscope relies on a tip that is positioned within 2nm of the surface and measures the electron density of the surface.They were awarded the Nobel prize in 1986 for this work

Nanotechnology Milestone….

Discovery of Fullerene [1985]

- A new form of carbon is discovered: C60



Fullerene

- Richard Smalley, Robert Curl and Harold Kroto discovered C60 while investigating the outer atmosphere of stars, for which they were awarded the Nobel Prize in 1996. Officially known as buckminster fullerene, C60 is more commonly known as a buckyball as the 60 carbon atoms are arranged into a sphere made of 12 pentagons and 20 hexagons (exactly like a football).

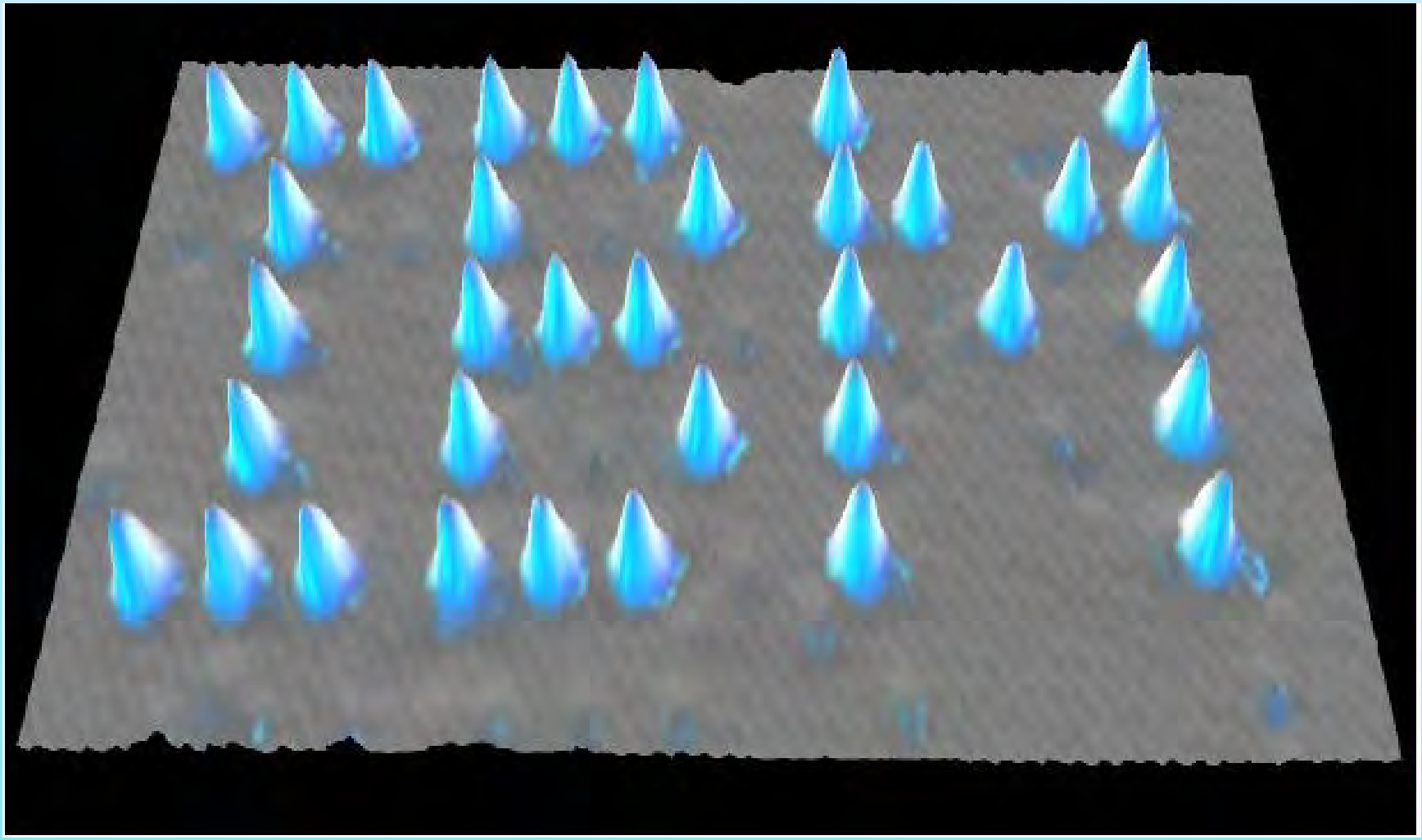
Nanotechnology Milestone….

Control the position of atoms [1990]

IBM demonstrate ability to control the position of atoms

- IBM research scientist Don Eigler showed that the position of atoms could be controlled precisely. Using the STM he manoeuvred 35 xenon atoms on a nickel surface so that they spelled out ‘IBM’. This was achieved at high vacuum and in the supercooled temperature of liquid helium.

Nanotechnology Milestone….

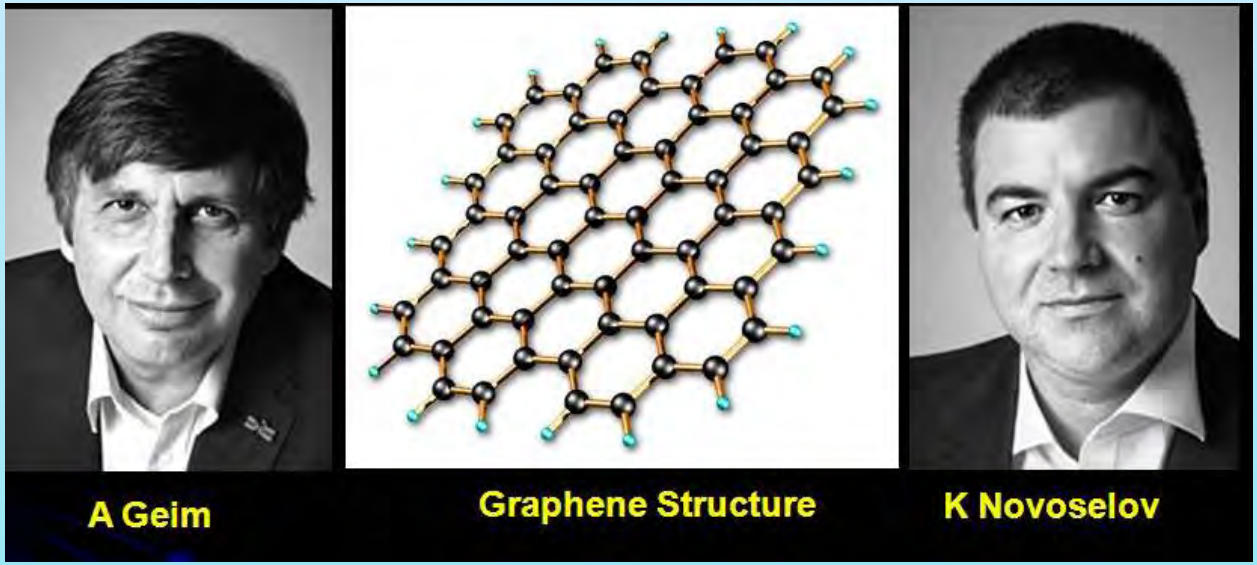


In 1989, Don Eigler arranged these xenon atoms, one by one, on a nickel surface to spell out the name of his company. (using a Scanning Tunneling Microscope)

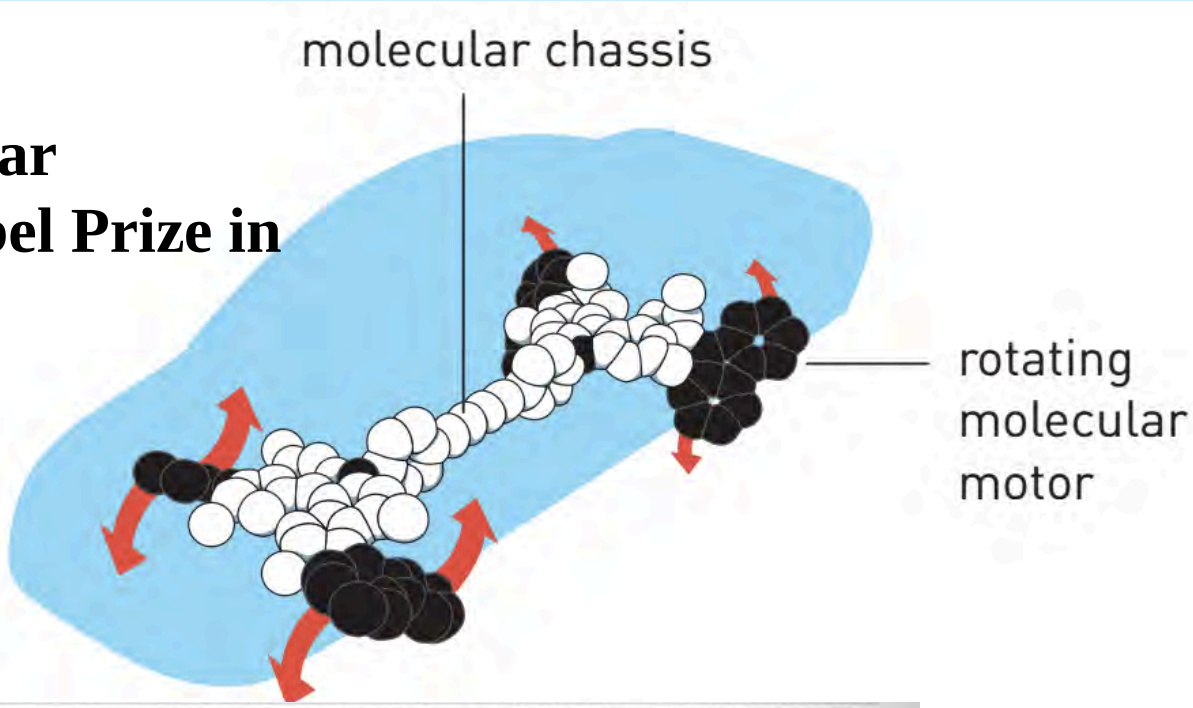
Carbon nanotubes [1991]

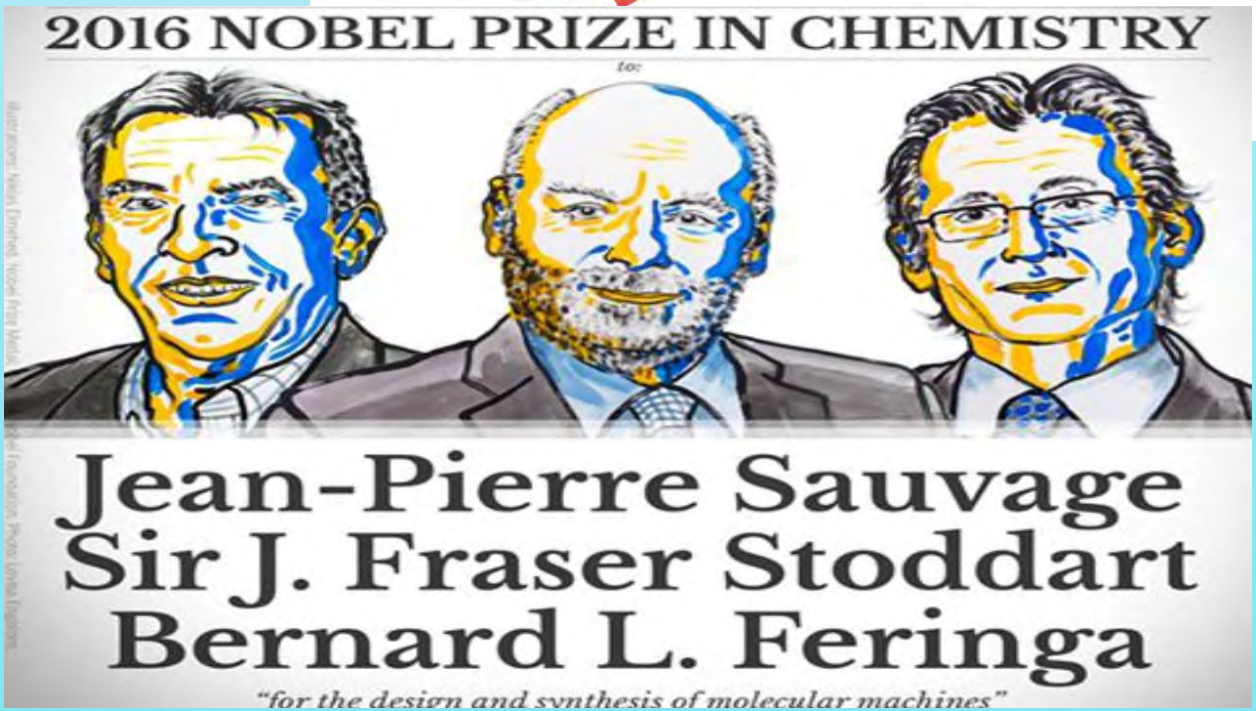
- Sumino Iijima discovered a process to make ‘graphitic carbon needles ranging from 4nm to 30nm in diameter and 1 micron in length’ (*Nature* 354, 1991, 56). The needle-like tubes he described consisted of multiple sheets of graphite rolled into hollow tubes, which have now become known as carbon nanotubes. In 1993 the first single-walled nanotubes (SWNT) were produced.

Nanotechnology Milestone….


A Geim
Graphene Structure
K Novoselov

Nanocars and 'molecular machines' take the Nobel Prize in Chemistry





Sauvage, from Strasbourg University, linked two ring-shaped molecules together to create a chain – called a catenane – in 1983

Eight years later, Stoddart, from Northwestern University, created a rotaxane – by threading a molecular ring onto a thin molecular axle and demonstrated it being able to move along the structure.

In 1999, Feringa, a professor at University of Groningen made a molecular rotor blade to spin continually in the same direction. "Using molecular motors, he has rotated a glass cylinder that is 10,000 times bigger than the motor," the Nobel committee said. Since then the work by Feringa has been consolidated and a 'nanocar' has been built

Quantum dots [1993]

First high-quality quantum dots prepared

- Murray, Norris and Bawendi synthesize the first high quality quantum dots of nearly monodisperse CdS, CdSe and CdTe (*Journal of the American Chemical Society*, 1993, 115).
- Quantum dots are very small particles with interesting optical properties: they absorb normal white light and, depending on their size, emit a range of bright colours. This property arises directly from the very small size of the particle.

Nanotechnology Milestone….

Nanoparticle embedded clothing [2002]

- Clothing embedded with nanoparticles that produce a stain-repellent coating has been developed. Nano-care™ khakis have the fabric fibres coated with nanowhiskers 10–100nm in length. This new stain-repellent fabric is available from a number of high street retailers and is available in trousers, shirts and ties.

Nano-solar cells [2003]

- Prototype solar cells have been made by Nanosolar Inc. in California. They use conducting polymers and nano-based particles. This technology has great advantages, compared to that for traditional silicon-based solar cells, including making the products much cheaper and easier to make. These cells are also produced in flexible sheets, making them suitable for many applications.

a nanometer (nm) is a billionth (10^{-9}) meter (1000 μm or 10 Å)

Nanotechnology is...

the ability to work at the molecular level, atom-by-atom, to create large structures with fundamentally new molecular organization.

Size

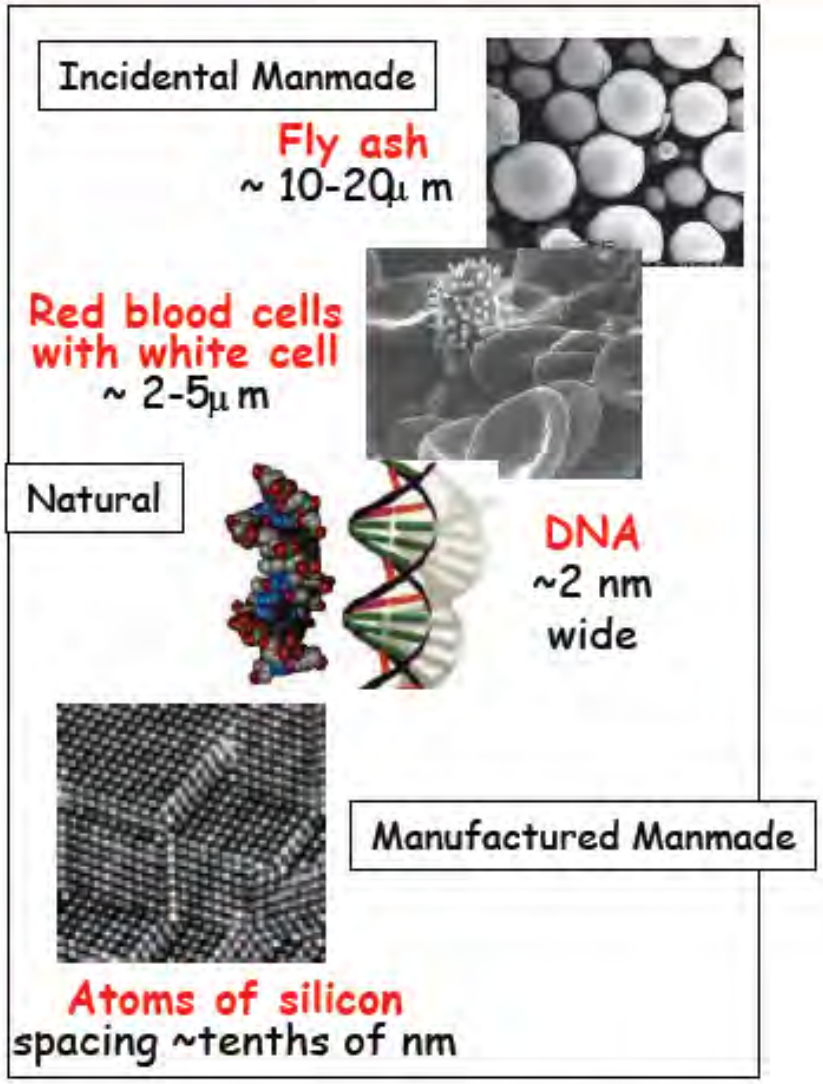
Research and technology development at the atomic, molecular or macromolecular levels, in the length scale of approximately 1 - 100 nanometer range.

Structure

Ability to control or manipulate on the atomic scale.

Novel properties

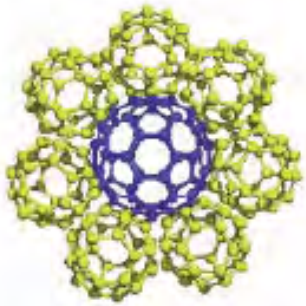
Creating and using structures, devices and systems that have novel properties and functions because of their small and/or intermediate size.

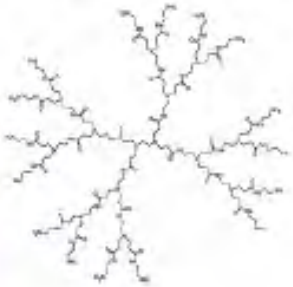


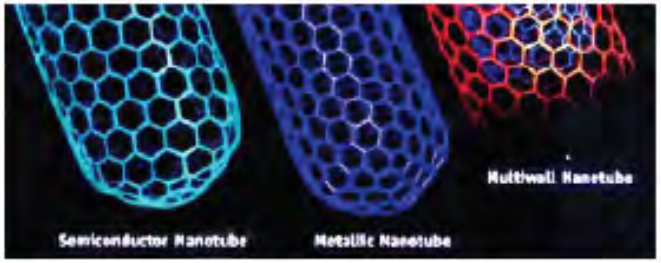
The ultimate goal is to build essentially anything from scratch, atom by atom

Keep in mind

Nanotechnology does not include just a single material or class of materials



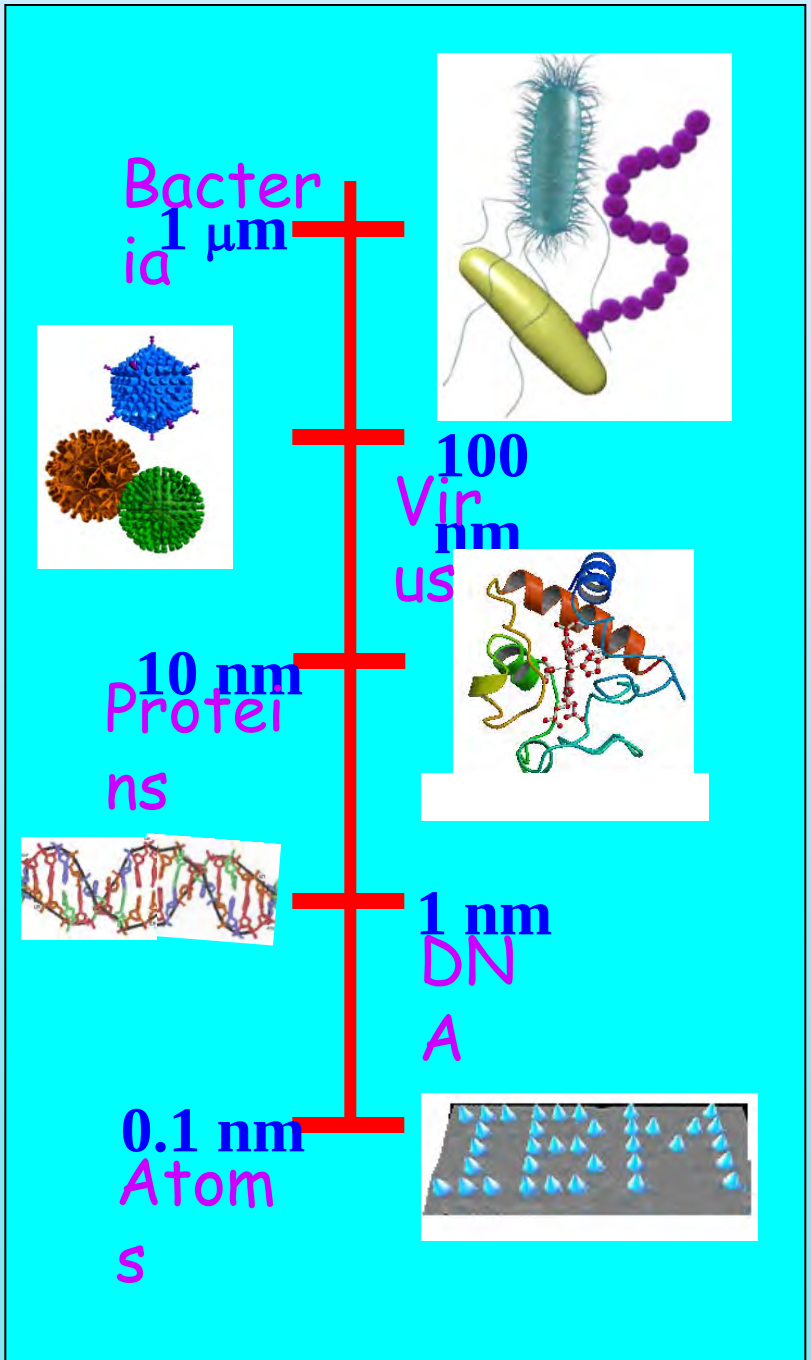




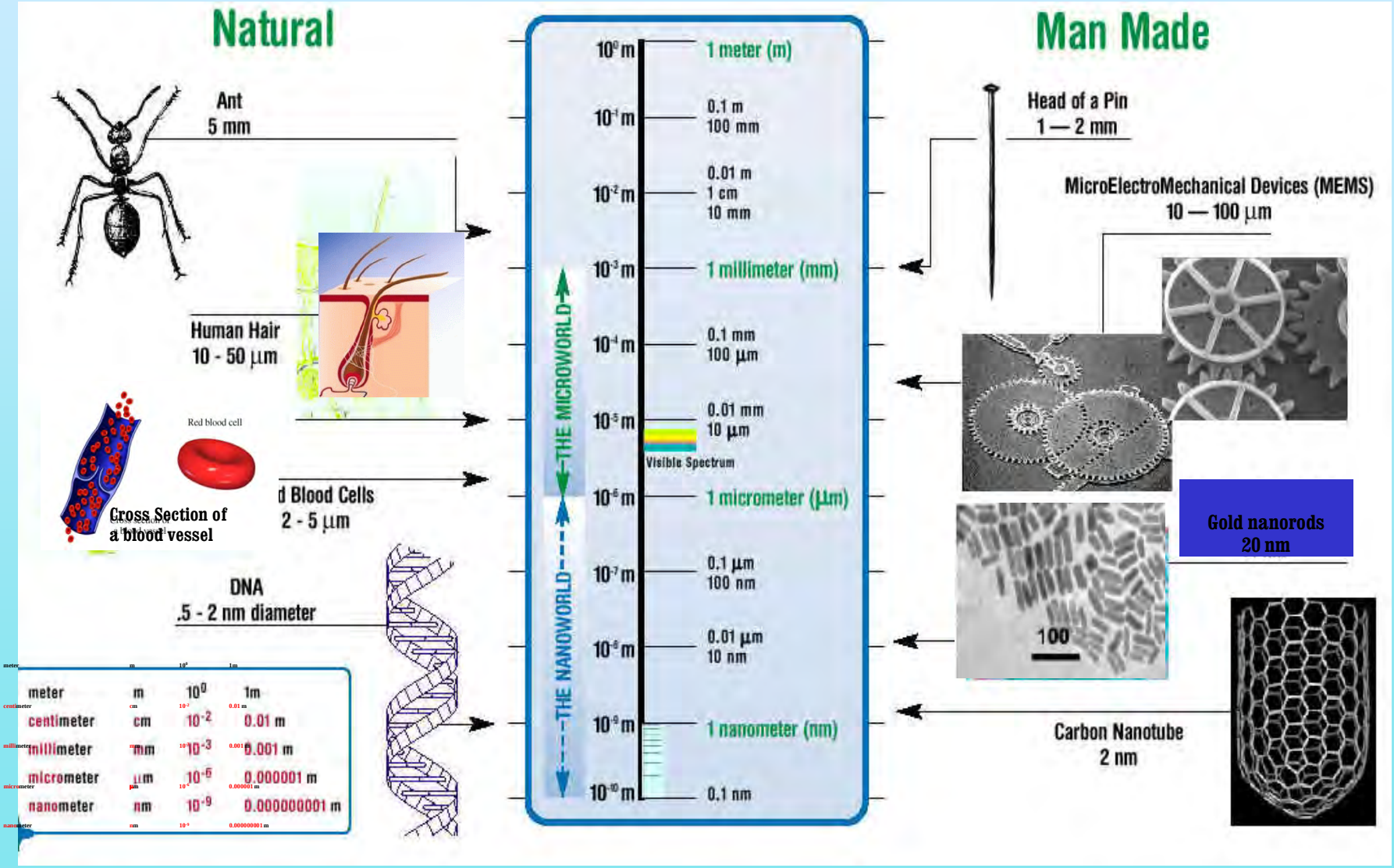
Nanotechnology does not include just a single industry or industrial sector

Nanotechnology converges with other technologies: biotechnology, information technology

Nanoscale materials



What is 'nanoscale'



Scale of Things

Object	Size
Width of hair	50,000 nm
Red blood cell	7,000 nm
Bacterium	1,000 nm
Virus	100 nm
Width of DNA	2.5 nm
Aspirin molecule	1 nm

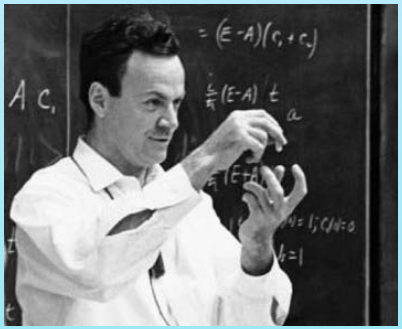
Nanoscience and Nanotechnology

Nanoscience -study of structures and materials on the scale of nanometers.

Nanotechnology is science, engineering, and technology conducted at the nanoscale, which is about 1 to 100 nanometers where unique phenomena enable novel applications.

The ideas and concepts behind nanoscience and nanotechnology started with a talk entitled **"There is plenty of Room at the bottom "** by physicist **Richard Feynman** and is known as **the father of** nanotechnology. In 1959

Professor Norio Taniguchi coined the term nanotechnology.



These phenomena are based on

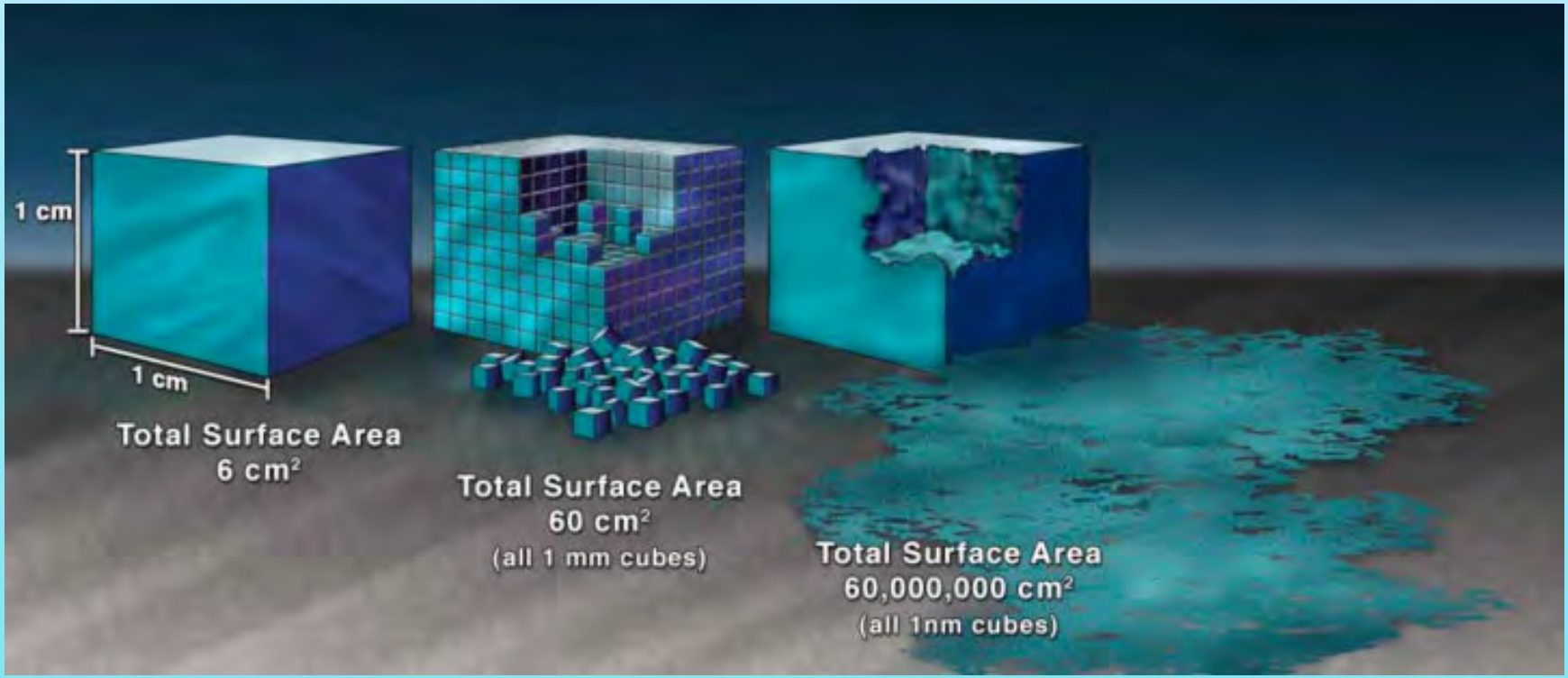
- **expanded surface area**
- **quantum effects**

Fact :Although modern nanoscience and nanotechnology are quite new, nanoscale materials were used for centuries. Alternate-sized gold and silver particles created colors in the stained glass windows of medieval churches hundreds of years ago. The artists back then just didn't know that the process they used to create these beautiful works of art actually led to changes in the composition of the materials they were working with.

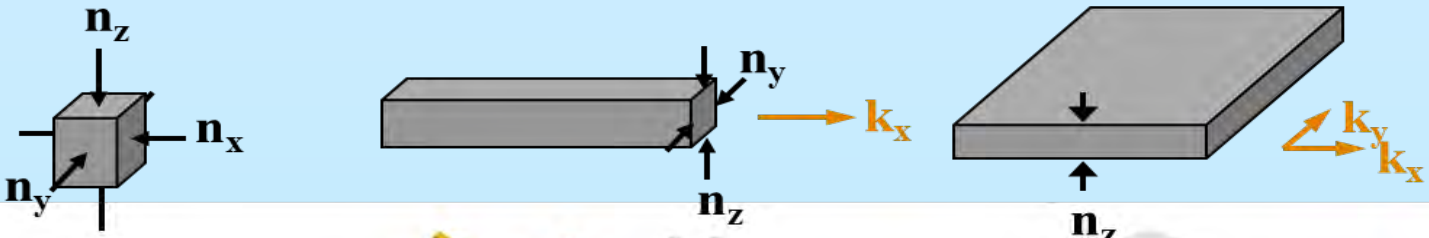
Expanded surface area

First, **nanomaterials** have a relatively larger surface area when compared to the same mass of material produced in a larger form.

- make materials more chemically reactive
- and affect their strength or electrical properties.

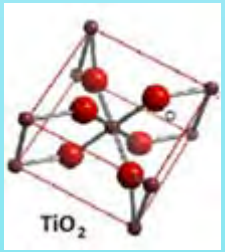


Types of nanoparticles



0D ;X,Y,Z **1D ; X,Y** **2D ; X** **3D**

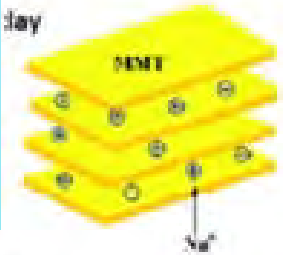
0-D: All dimensions at the nanoscale

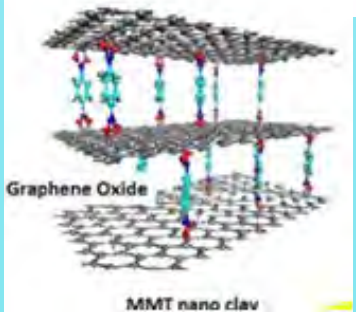


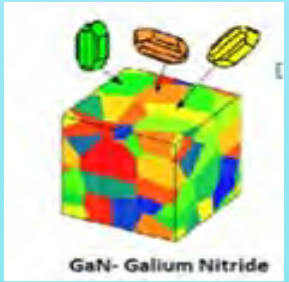
Carbon nano tubes

1-D: Two dimensions at the nanoscale, one dimension at the macroscale

2-D: One dimension at the nanoscale, two dimensions at the macroscale



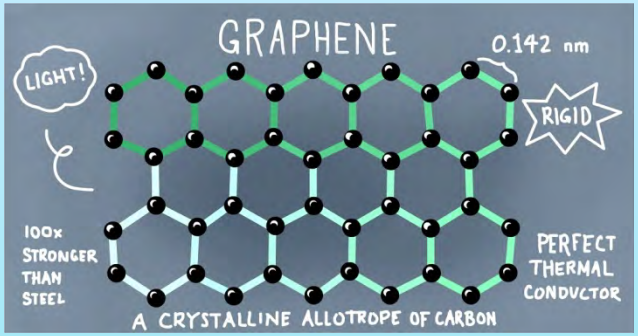


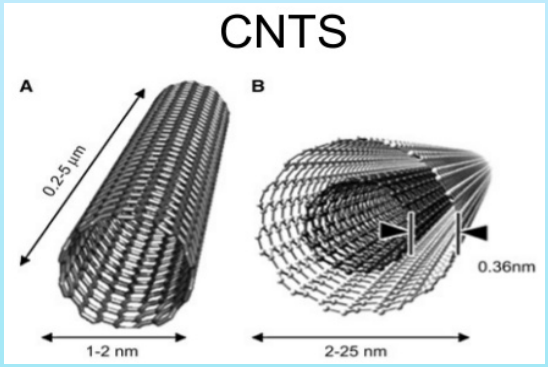


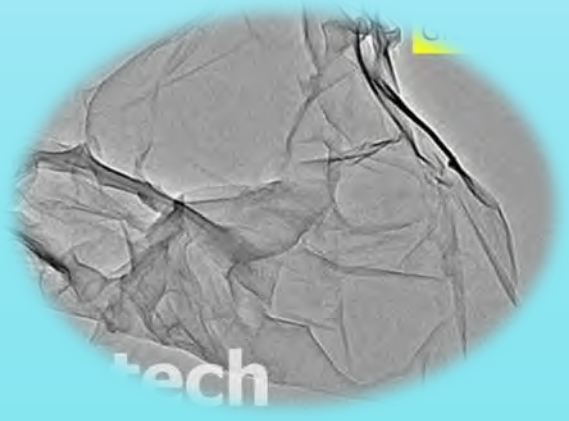
3-D: No dimensions at the nanoscale, all dimensions at the macroscale

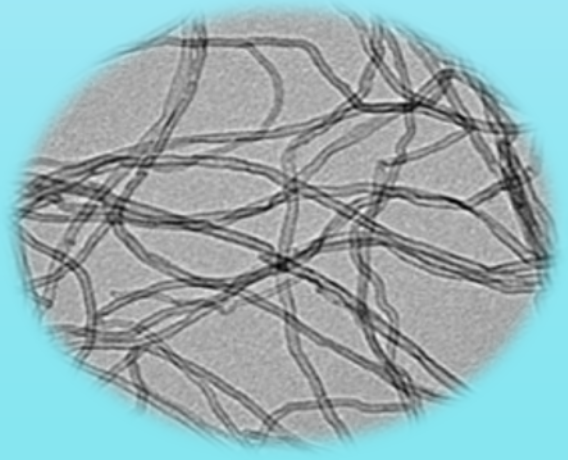
Potential Nanocomposite Materials

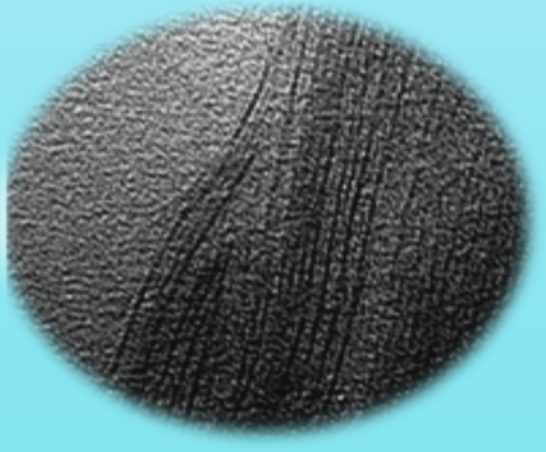
- Nano tubes : Graphitic platelets; Meta oxides; nanoclays; Bio fibres (flax, hemp…)



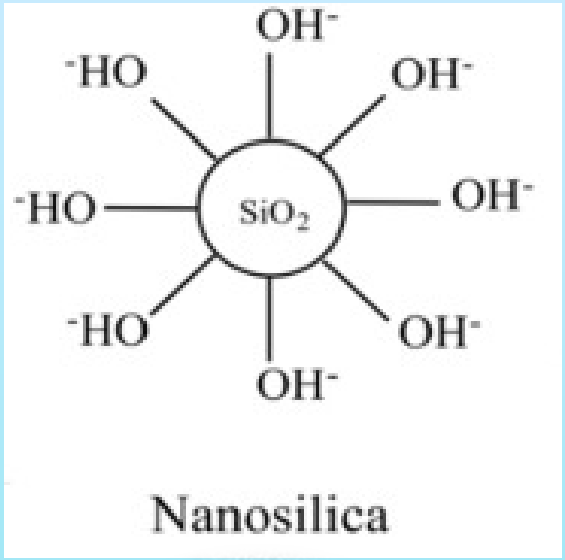




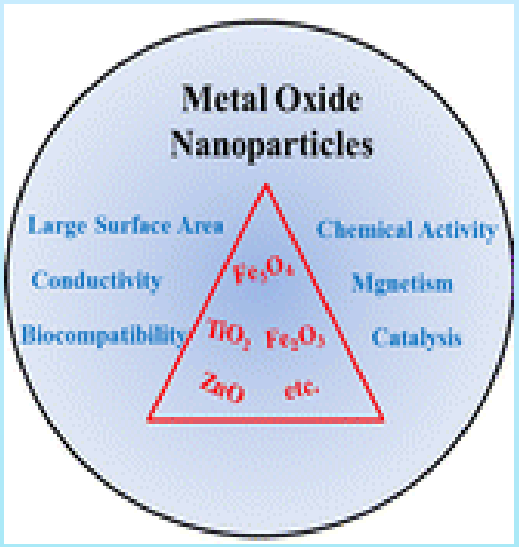




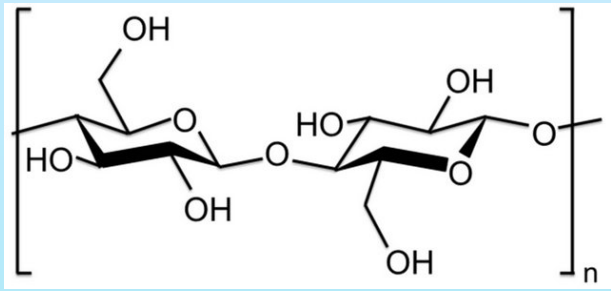
Potential Nanocomposite Materials. *Cont.....*



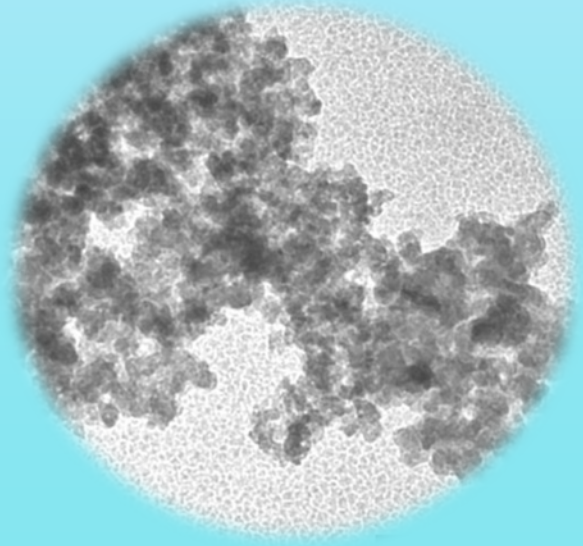
Nanosilica

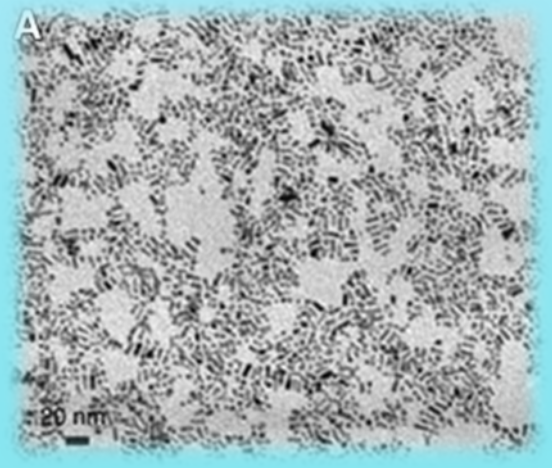


ZnO nanoparticles



Nanocellulose





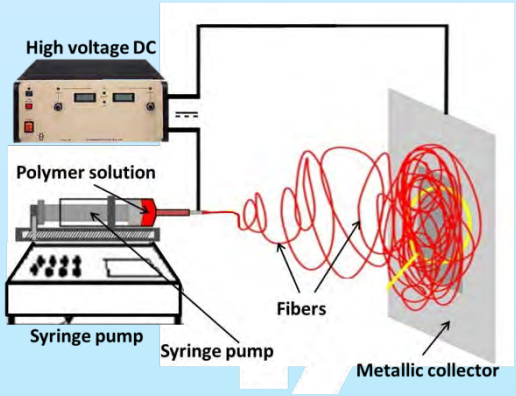
Nanotechnology: Potential Global Economic Impact in 15-20 Years

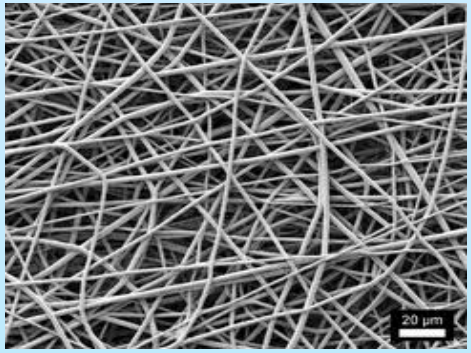
Materials; Materials Processing	**$340 Billion**
Devices in Information Technology	**$300 Billion**
Biotechnology/Pharmaceuticals	**$180 Billion**
Chemical Manufacturing, Catalysis	**$100 Billion**
Aerospace	**$70 Billion**
Sustainability – Ag., Water, Energy	**$45 Billion**
Healthcare – Diagnostics, Prosthetics	**$30 Billion**
Tools, Automation, Life Cycle Costs	**$20 Billion**
Total	**~ $ 1 Trillion**

Ref.:Dr. Mihail Roco, NSF;NanoBusiness Alliance;J. S. Murday, AMPTIAC Quarterly, Volm. 6, No. 1, p. 7

Biomedical Applications

Present approach



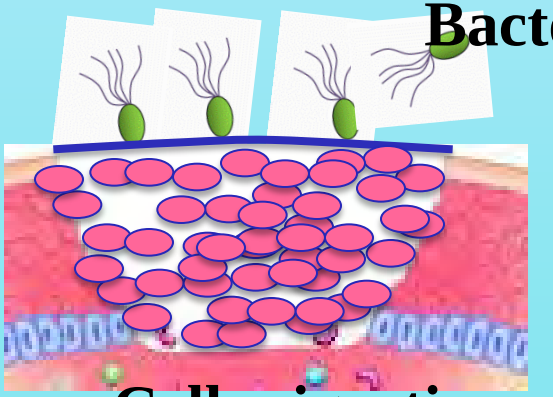


Wound

Skin substitute applicatio

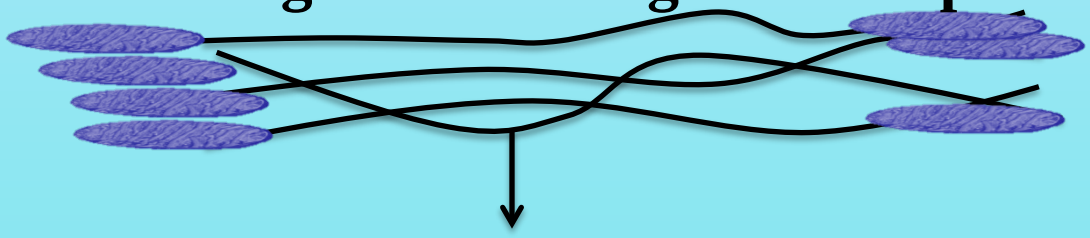
Healed wound

Bacteria



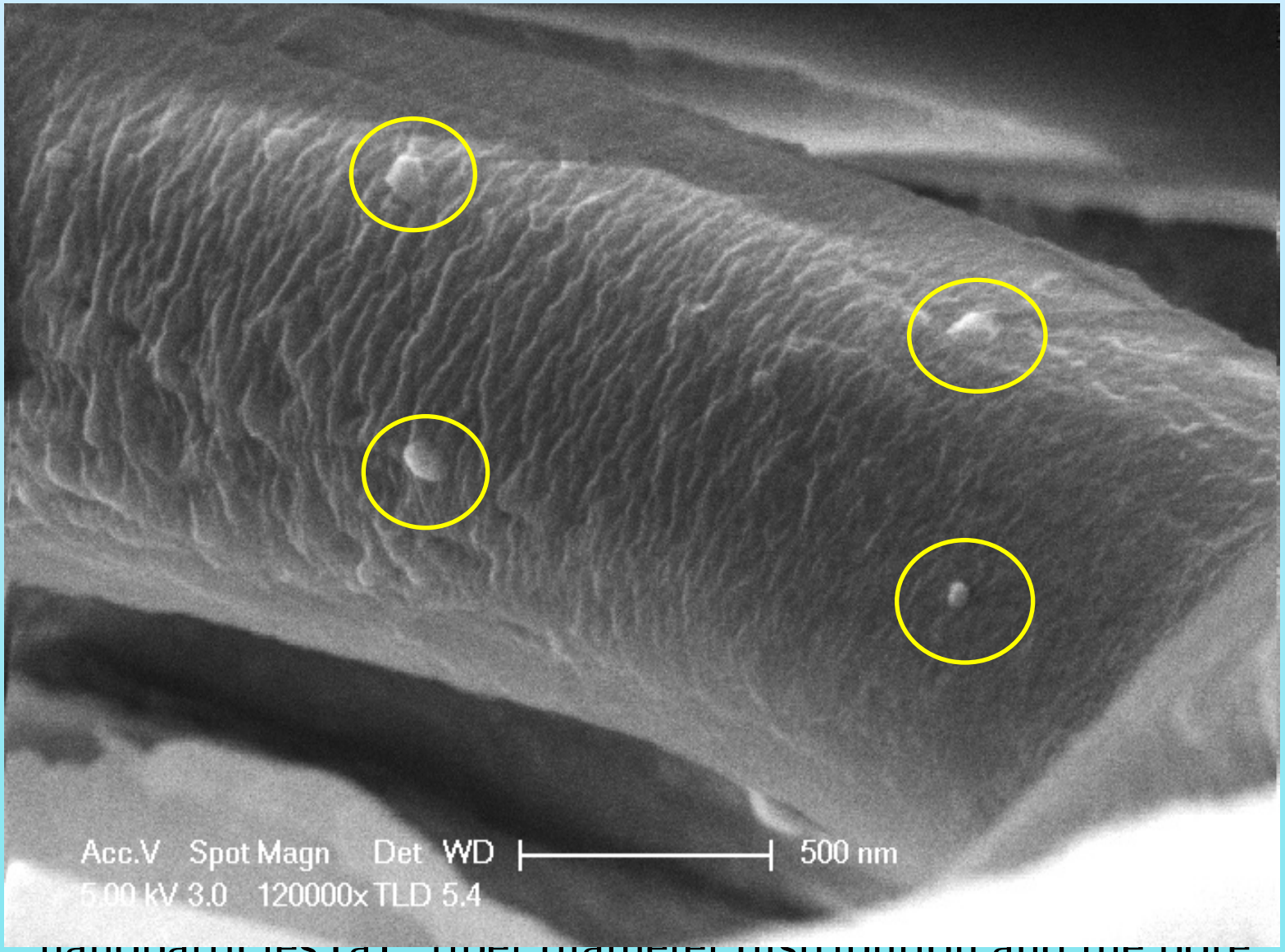
Cell migration

Cell migration through electrospun mem



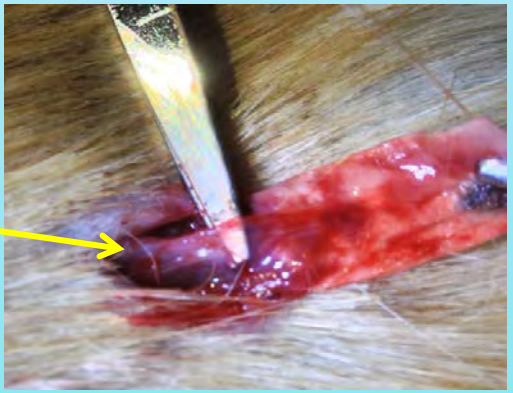
Electrospun fibres

Morphology, RSC advances, 2015



nanoparticles (a), fiber diameter distribution and the pore space distribution (c).

Implantation in Guinea pigs



Wound Healing Activity

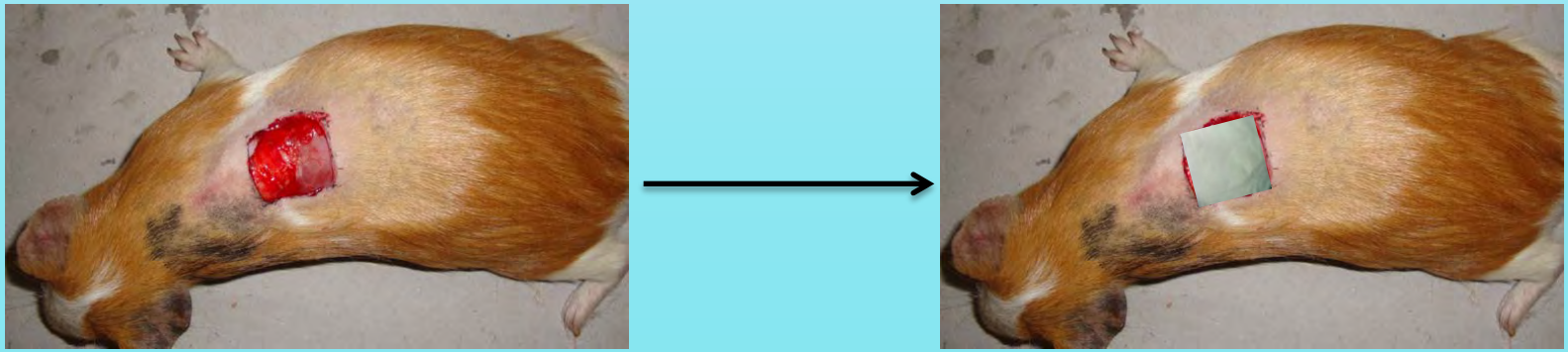
A 2 X 2 cm full thickness skin excision wound was made and PCL membranes with 2 X 2 cm dimensions were sutured on the wounds and the photographs were taken each day until the wounds were perfectly healed.

Positive control (Povidone- Iodine (Betadine® ointment) and negative control groups were also maintained.

The percentage of wound healing was calculated using the formula,

$$W^{\%} = \frac{[WA^0 - WA^t]}{WA^0} \times 100$$

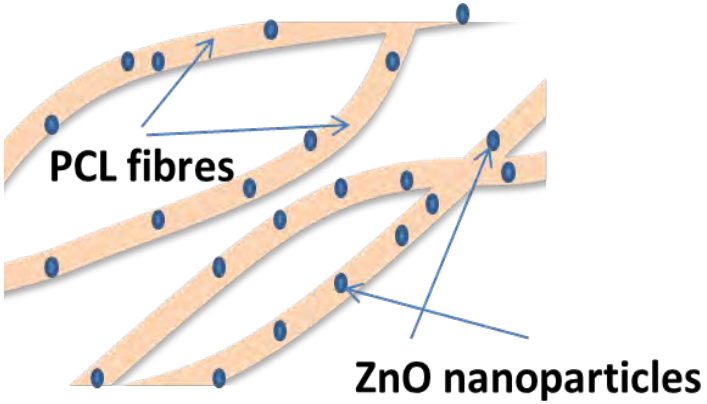
where $W^{\%}$ is the percentage of wound healing, WA^0 is the area of wound at 0^{th} day and WA^t is the area of wound after different days of healing.

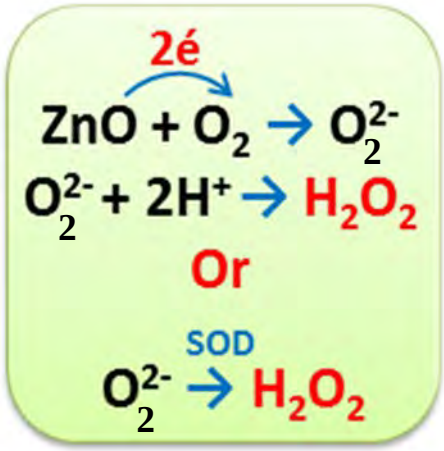


The approach

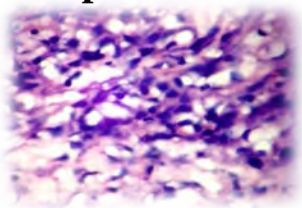
Electrospun PCL/ZnO nanoparticles membrane

NANOSCALE,2015

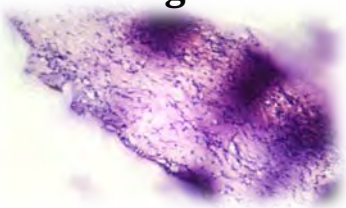




Cell proliferation

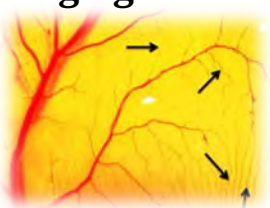


Cell migration

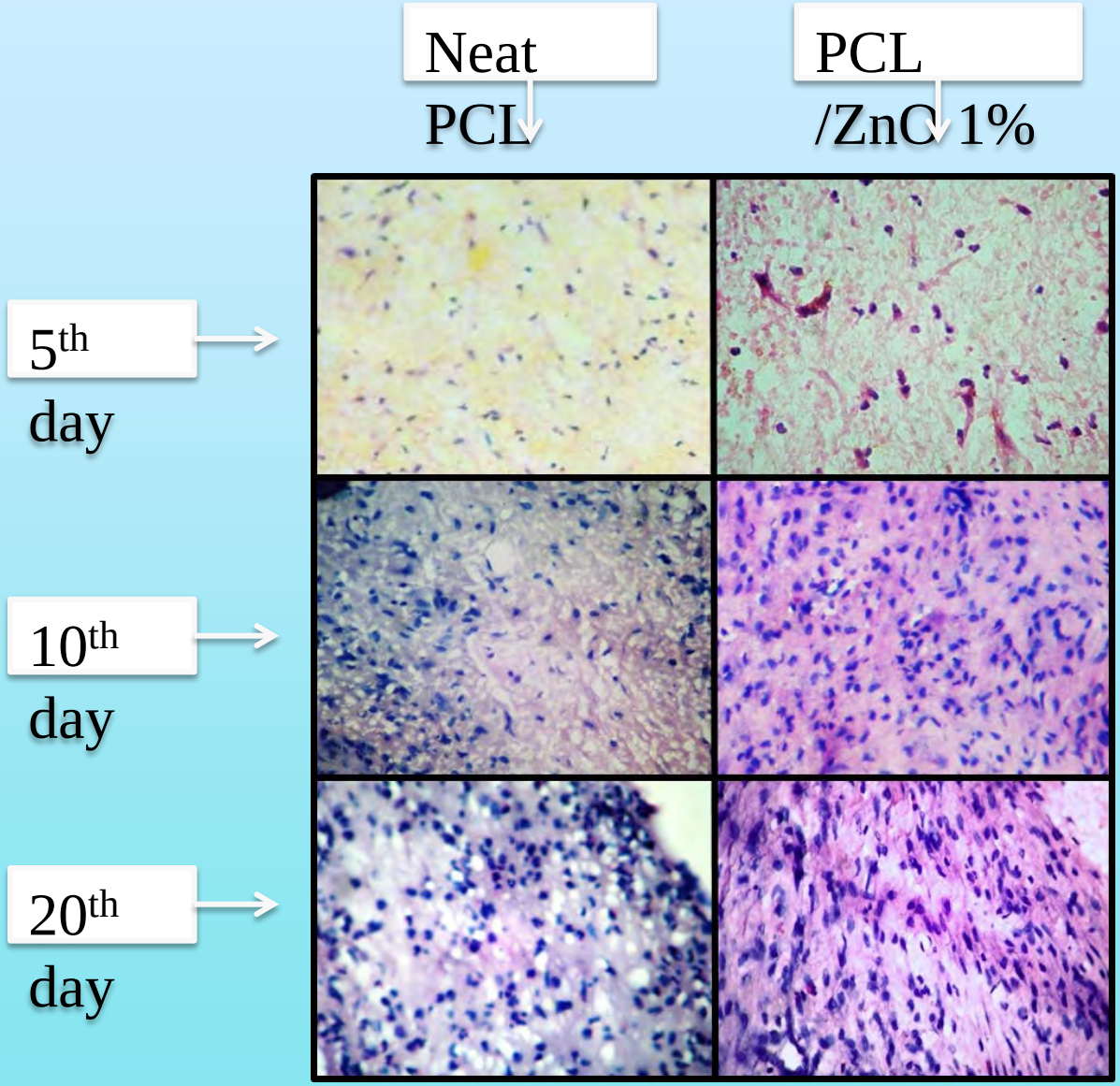


Wound healing

Angiogenesis

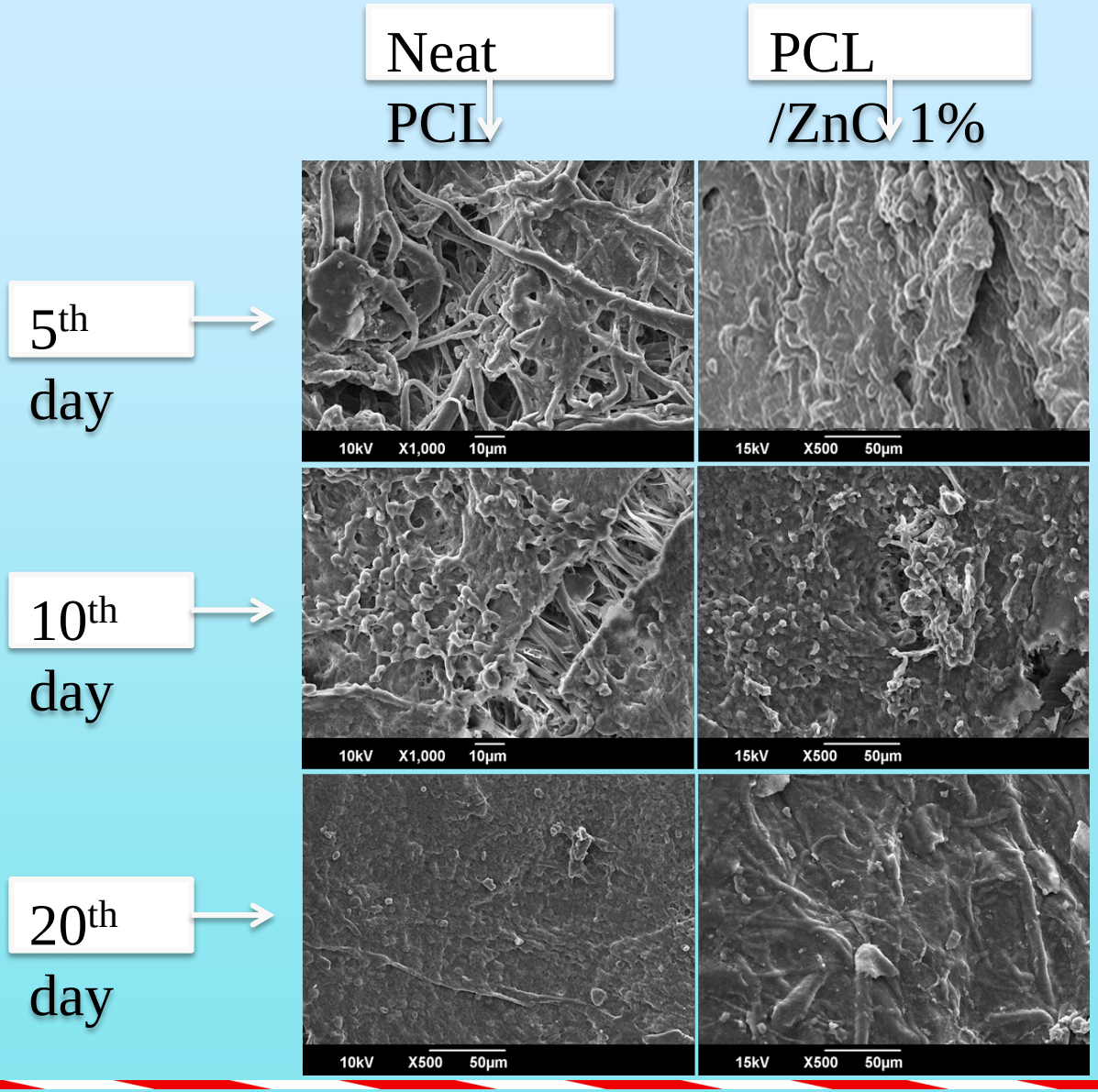


Histology



Augustine, R., Dominic, E. A., Reju, I., Kaimal, B., Kalarikkal, N., & Thomas, S. (2014). ***RSC Advances*** 4 no. 48 (2014): 24777–24785.

SEM after implantation



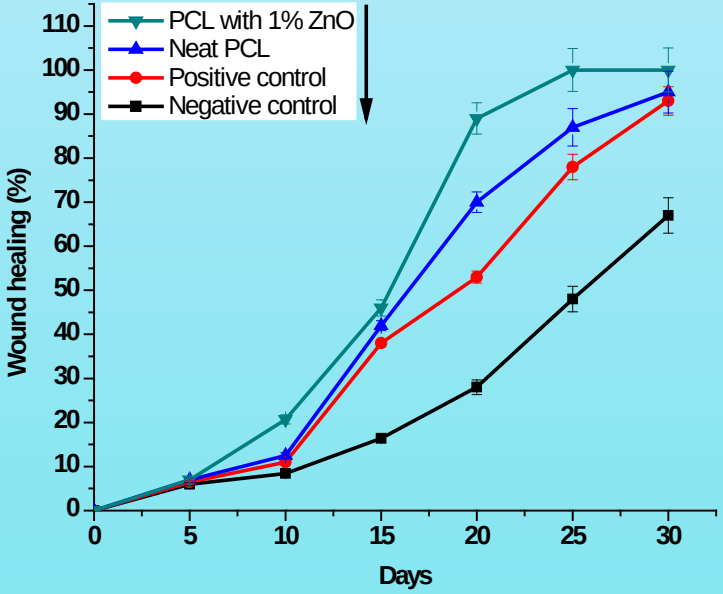
Augustine, R., Dominic, E. A., Reju, I., Kaimal, B., Kalarikkal, N., & Thomas, S. (2014). ***RSC Advances*** 4 no. 48 (2014): 24777–24785.

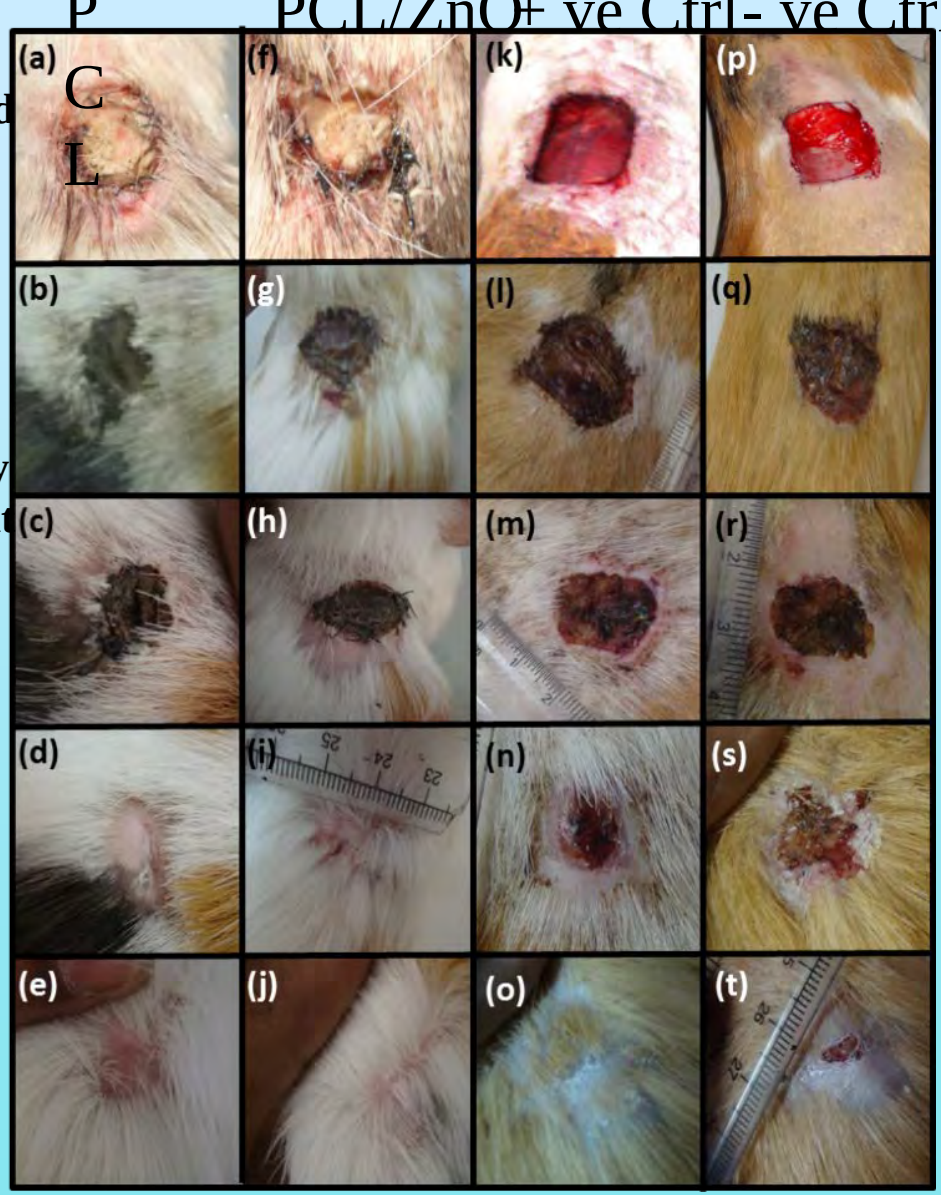
Wound healing

Percentage of wound healing was calculated using the formula,

$$W^{\%} = \frac{[WA^0 - WA^t]}{WA^0} \times 100$$

Where $W^{\%}$ is the percentage of wound healing, WA^0 is the area of wound at 0^{th} day and WA^t is the area of wound after different days of healing.





Augustine, R., Dominic, E. A., Reju, I., Kaimal, B., Kalarikkal, N., & Thomas, S. (2014). ***RSC Advances*** 4 no. 48 (2014): 24777–24785.

The U.S. government's research agenda for nanomedical applications was defined in June 2000 at a conference organized by NIH's Bioengineering Consortium, at which about 600 scientists, physicians, and engineers identified eight topics for research in the coming years:

- Synthesis and use of nanostructures
- Applications of nanotechnology in therapy
- Biomimetic nanostructures,which are synthetic products developed for man

  understanding of biological systems.
- Biological nanostructures
- The electronic–biologicalinterface
- Devices for early detectionof disease

Biomedical….

Nanodrugs

- Carbon buckyballs and nanotubes might be useful as drug delivery vehicles

  because their nanometer size enables them to move easily inside the body.

- The active compound might be inserted in a nanotube or bonded to a particle's

  surface.

In April 2002, American Pharmaceutical Partners (Los Angeles) presented results from an early human trial of ABI-007, a new nanoparticle delivery system

for an established anticancer drug. ABI-007 is 130 nm long and consists of an engineered protein-stabilized nanoparticle

paclitaxel, which is used to treat breast, bladder, an a dozen other cancers.as VIRUS

A Bioengineered cell rover swims through the human body, performing drug delivery, waste removal and cell repair

Biomedical….

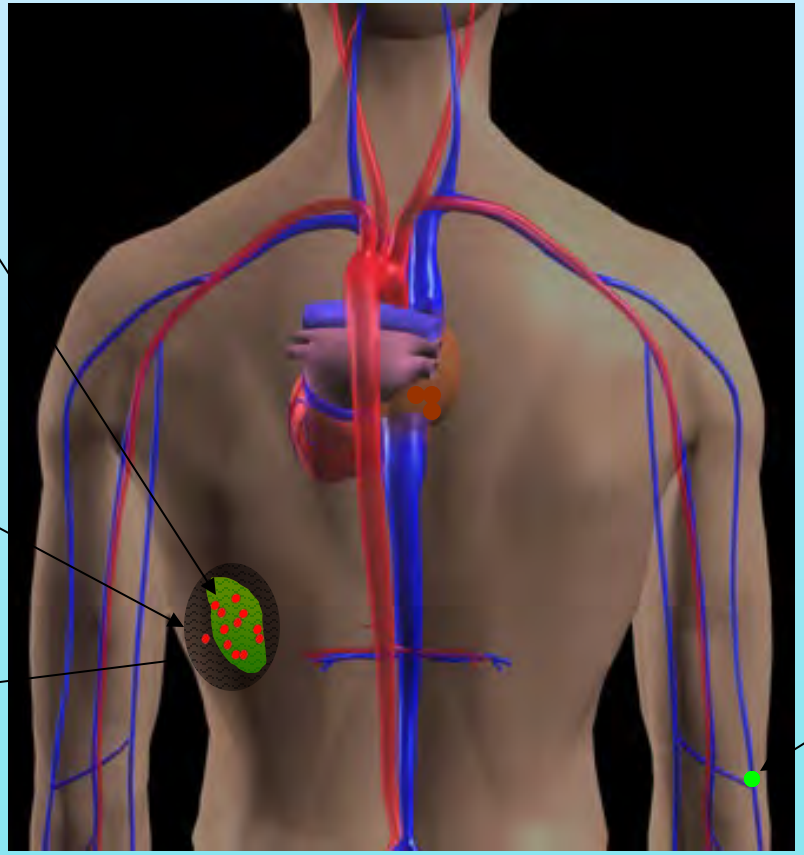
Nanomaterials - Biomarkers

- 15nm dia FeO nanoparticles injected directly into tumor site.
- Alternating magnetic field (similar to MRI) heats up nanoparticles, destroying tumor from inside with minimal damage to surrounding tissue

How would it work?

Solid tumor

Apply magnetic field to concentrate particles



Modulate field to release drug from particles
Or
to produce heat

Other options for targeting:

1 - Direct injection into tumor site,

2 - Coating NMP with antibodies to target tumor

Inject NMPs, NMP will circulate through the blood stream

Gentle **cancer treatment** using **nanoparticles** works. ... The tumor is **treated** with **nanoparticles**, which are injected directly into the tumor and are then flashed with near infrared laser light. The laser light heats the **nanoparticles**, thus damaging or killing the **cancer** cells.Aug 3, 2016

Medical Plastics

Medical Tubing and Thin Films

- **Market Trends**
  - Specialty tubing and stent-delivery balloons with very small diameter (< 200μm) and ultra-thin wall (< 2.5μm) used in the catheters inserted into the cardiovascular system

- **Advantages**
  - High bending stiffness, pull/push strength, kinking and buckling resistance and, good toughness.
  - Extraordinary smooth surface finishing
  - Good scratch resistance

Medical plastics…..

Automotive Parts

Toyota (later 1980s): the first nanocomposite (nylon-6/5wt% clay) for heat-resistant timing belt covers for Toyota vehicles.

Property Enhancement

- Tensile strength 40%
- Tensile modulus 68%
- Flexure modulus 126%
- Heat distortion temperature 65°C to 152°C

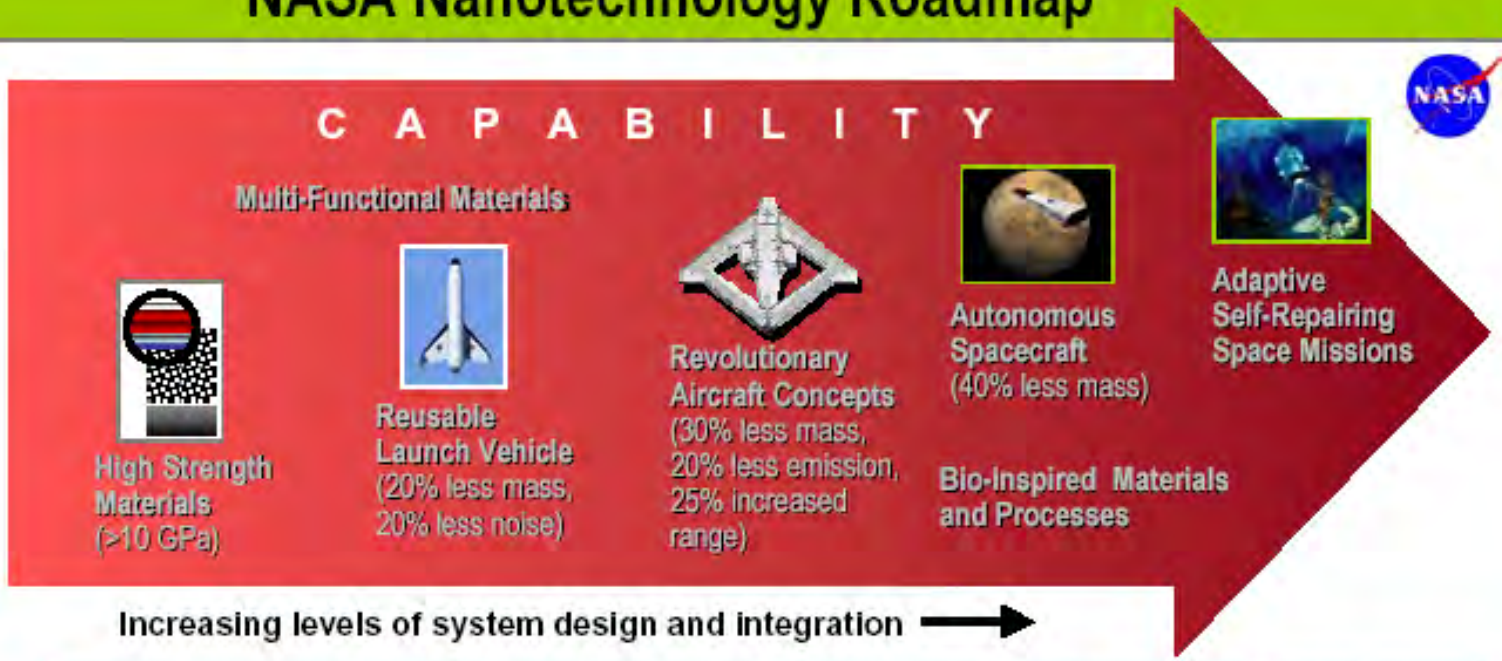
General Motors (2004): TPO/clay nanocomposites to exterior trim of Chevrolet Impala.

Advantages

- Higher stiffness
- Weight saving
- Improved surface quality
- Less brittle in low temperatures
- Easily recyclable

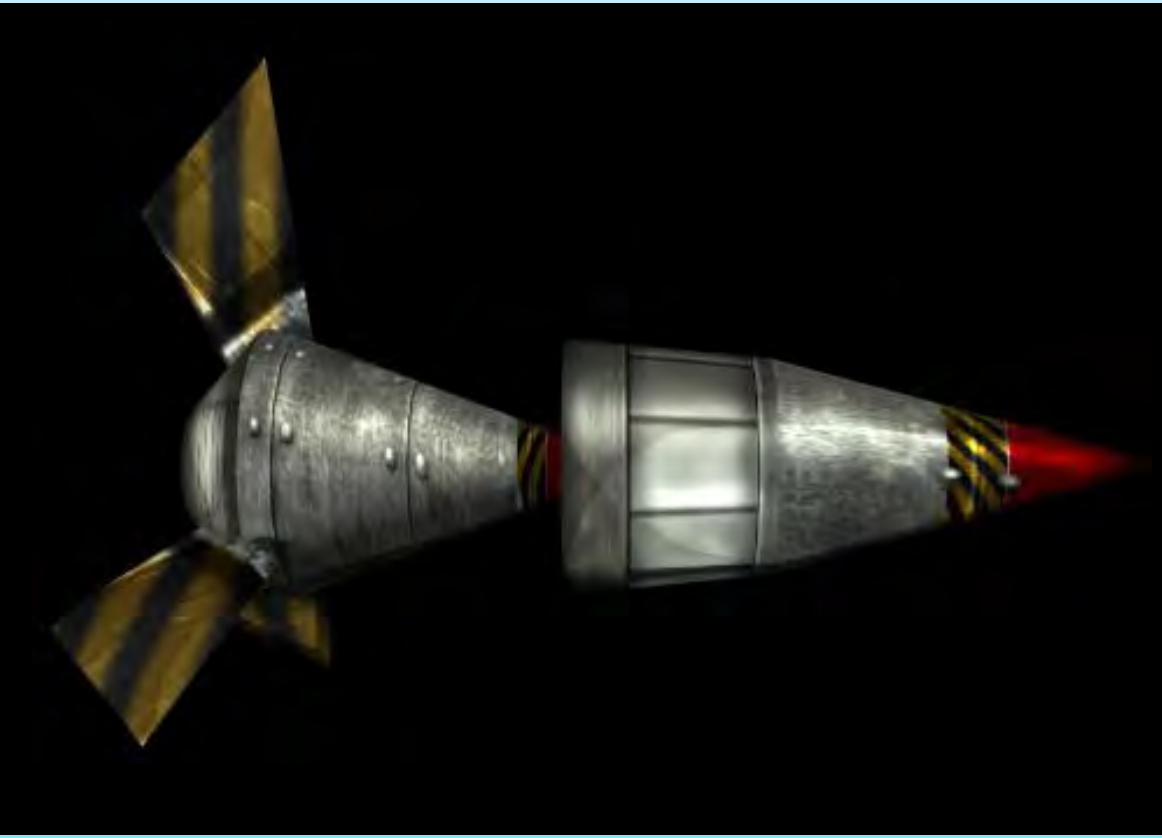
Automobiles……

NASA Nanotechnology Roadmap



	2002	2004	2006	2011	2016
Materials	• Single-walled nanotube fibers	• Nanotube composites	• Integral thermal/shape control	• Smart "skin" materials	• Biomimetic material systems
Electronics/ computing	• Low-Power CNT electronic components	• Molecular computing/data storage	• Fault/radiation tolerant electronics	• Nano electronic "brain" for space Exploration	• Biological computing
Sensors, s/c components	• In-space nanoprobes	• Nano flight system components	• Quantum navigation sensors	• Integrated nanosensor systems	• NEMS flight systems @ 1 μW

Nano Weapons



- *Easy to build*
- *Hard to monitor*
- *Easy to deliver*
- *Obsolete almost immediately*
- *Programmable and controllable*

Surface Coating

Super-tough and Transparent Nanocomposite for Scratchproof Coating

An epoxy based matrix plus nanometer-sized particles produced a transparent, super-tough and highly abrasion resistant and chemical resistant coating for transparent substrate. Other benefits include

- do not craze, crack or shatter upon impact
- flame resistant
- effective barrier against moisture and oxygen

Potential commercial applications are protective eyewear and vehicle wind-shields etc.

Surface coating…

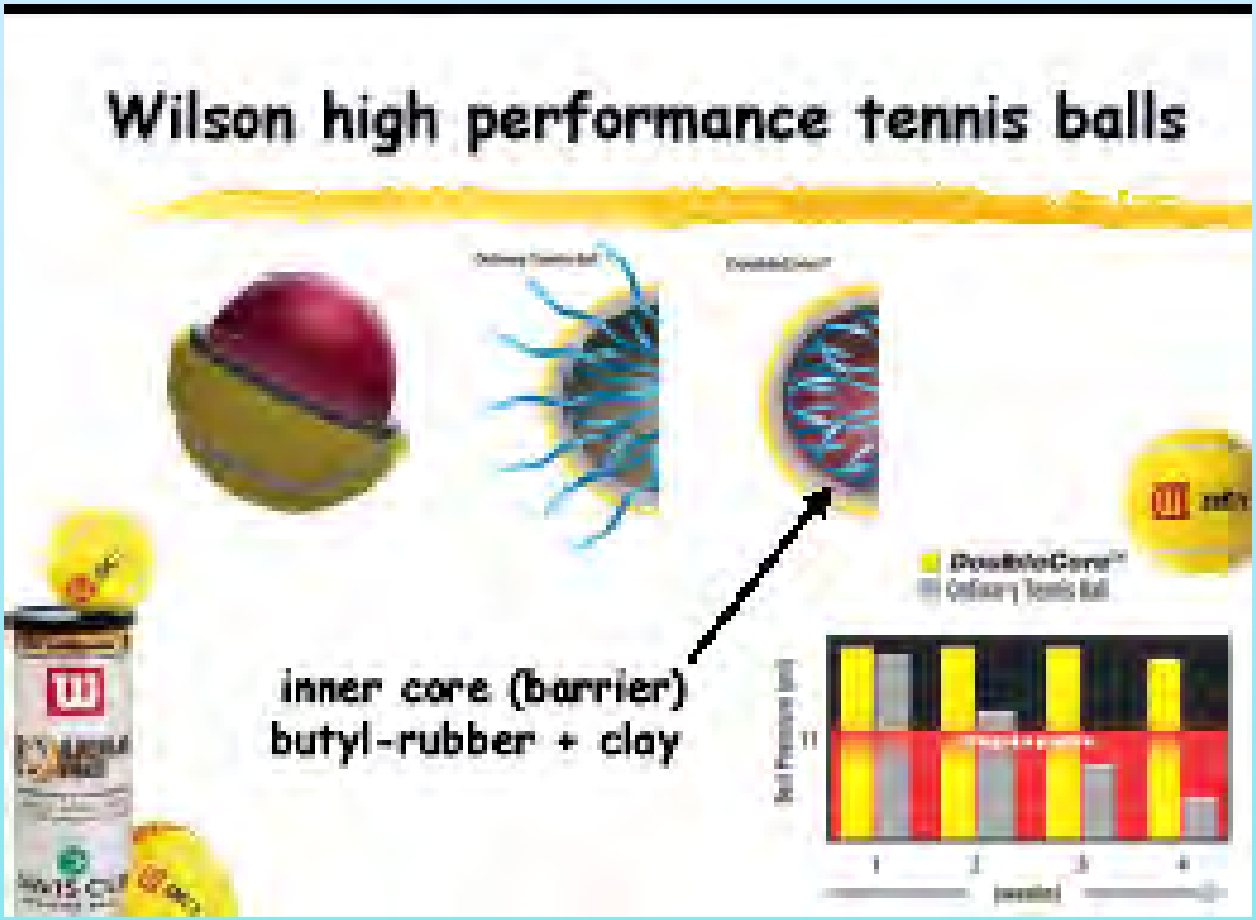
Flame Retardant Materials

Addition of nanofillers will greatly improve flame retardancy of polymer resins. The nanofillers delay ignition, reduce smoke emissions and eliminate slumping and dripping of the molten polymer by formation of a strong, stable char. The some applications of the flame retardant nanocomposites are

- wire and cable covers
- battery jars and electrical enclosures
- small appliances
- home interior decoration materials

PP Nanocomposite PP Halogen Neat PP Vinyl

Sports


Wilson high performance tennis balls
inner core (barrier)
butyl-rubber + clay

Improved Tires
Air retention without weight, rolling resistance and cost penalties.

- Tire Company Primary Driver:
  - Cost reduction: materials and processing
- Other Potential Benefits:
  - Reduce fuel usage in US by 2.5 billion gallons /year
  - Reduce solid waste by ~1 billion lbs/year
  - Improved tire safety with reduced maintenance requirements
- Status:
  - Several leading tire companies evaluating technology
  - Seeking additional commercialization partners and government support

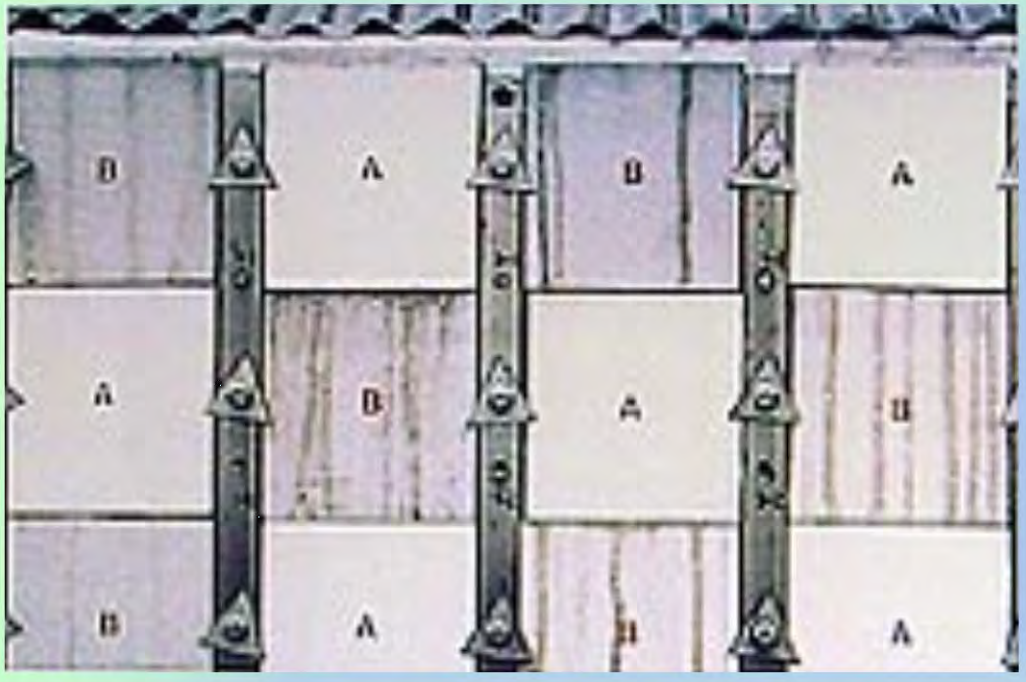
Chemical protection with improved dexterity and flexibility

- Military Applications:
  - Improved gloves
  - Facemasks
- Anti-terrorism:
  - Improved gloves and other chemical warfare protection
- Commercial:
  - Variety of laboratory, industrial and medical protective gloves

InMat will soon introduce a new product line: ChemWall™ coatings for use in chemical protective products utilizing a broader range of polymer matrices.

TiO_2 coated tent material

Titanium Dioxide can be coated on many building materials. These films exhibit a self cleaning effect due to the strong oxidizing properties.



TiO_2 coated exterior tiles

A. Tiles coated photocatyltic, superhydrophilic coating
B. ordinary painted wall tiles

TiO_2 coated glass

Anti-fogging glass. Generally when moist air comes in contact with glass, small droplets of water are formed, and the glass becomes fogged. On titanium dioxide coated glass, the water forms a continuous flat sheet, so that there is no fogging.

TiO_2 coated tiles in a hospital environment showed the surface bacteria on the wall surfaces were reduced to zero, plus airborne bacteria counts were reduced

Making fuel go further

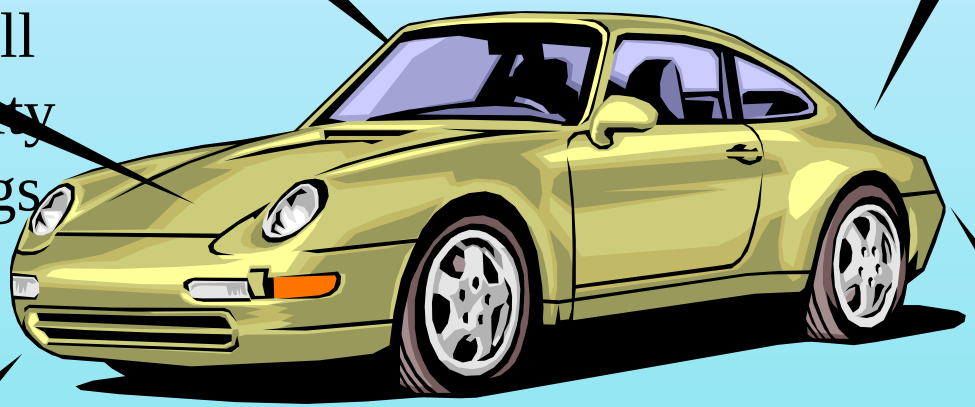
Mix a tiny amount of Envirox fuel additive with diesel, and the minuscule cerium-oxide nanoparticles help the fuel to burn better and clean up exhaust fumes.

Automotive example

Carbon nanotubes based alloys are being examined as a replacement for automobile frames

Nano-scale metal oxide cer catalysts will further reduc harmful emissions

Nano-powders and coatings will ncrease durability of paint coatings



- The unique combination of stiffness and toughness of nano polymer composites will make these lightweight materials ideal substitutes for steel. Nanopolymer composite

- Nano-catalysts and membrane technologies will play critical role in

But what are the possible down sides?

What are the risks to human health and the environment?

Unknown:

Toxicity

Fate, transport, transformation in the environment

Bioaccumulation in the food chain

Life Cycle impacts

Research is beginning,
but a much greater effort is needed to keep up with the technology

Is There a Risk in the Workplace?

- Nanomaterials present new challenges to understanding, predicting and

  managing potential health risks

- Risk -function of exposure and toxicity
- Exposure to nanomaterials &other toxic chemicals
- What is the potential for exposure?
  - How often, how long, and how?
  - Repetitive or isolated exposure?
  - Concerns about respiratory and dermal exposure to nanomaterials
- Toxicity of nanomaterials
  - What are the target organ(s)?

The Environment/Human Health Challenge

Use nanotechnology research to:

…Help clean up past environmental damage

…Correct present environmental problems

…Prevent future environmental impacts

…Help sustain the planet for …

Nanotechnology is a very powerful new approach that will change our industries and our lives. We have a very small window right now to bring up this technology responsibly and sustainably—to learn from past mistakes and concurrently look at the possibility of harmful implications as we benefit from the applications.

It's an opportunity too important to neglect.

Thank you for Your Attention

Nano Group