

# Introduction to Nano technology

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Centurion University**

# ***Nanotechnology Overview***

# ***Nanotechnology Overview***

- **What is nanotechnology**
- Scale and size
- Emergence of properties
- Nanotechnology examples and tools
- Driving forces behind nanotechnology
- Closing thoughts

# ***Numerous Nano Definitions***

- The study, design, creation, synthesis, manipulation, and application of functional materials, devices, and systems ***through control of matter and energy at the nanometer scale.***
- The study, creation, or manipulation of devices with atomic or molecular scale precision.
- Exploitation of novel phenomena, including the properties of ***matter, energy, and information*** at the molecular, atomic, and sub atomic levels.

# *Scale and Dimension*

Small *things*

Short *times*

Small *numbers*

Low *probabilities*

- Quantum mechanics come into play
  - Heisenberg uncertainty principle
- Things happen *differently at nanoscale*

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# 'Nano'

“Nano” = one BILLIONTH

1 nm = 1/1,000,000,000 of a meter  
= length 10 hydrogen atoms

Diameter of human hair ~50,000 nm

The smallest visible length to the human eye  
is 10,000 nm across



# *Orders of Scale*

Tera – trillion,  $10^{12}$

Giga – billion,  $10^9$

Mega – million,  $10^6$

Kilo – thousand,  $10^3$

Macro – referring to big or visible

Milli –  $10^{-3}$

Micro – referring to small, also  $10^{-6}$

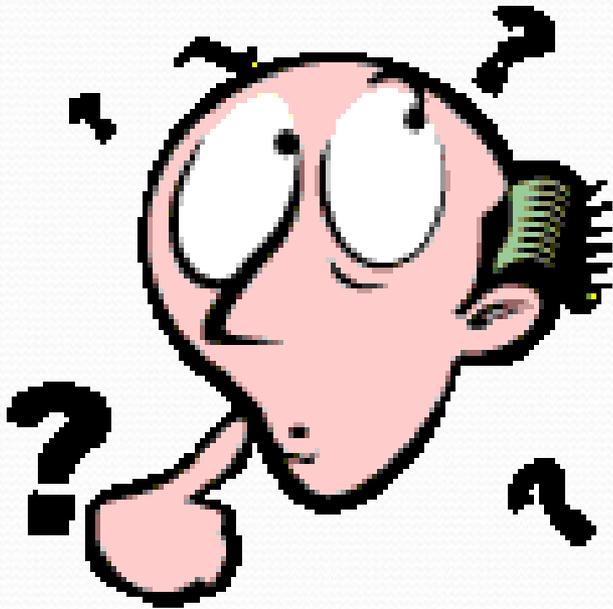
Nano –  $10^{-9}$

Angstro –  $10^{-10}$

Pico –  $10^{-12}$

Femto –  $10^{-15}$

# *Understanding Size*



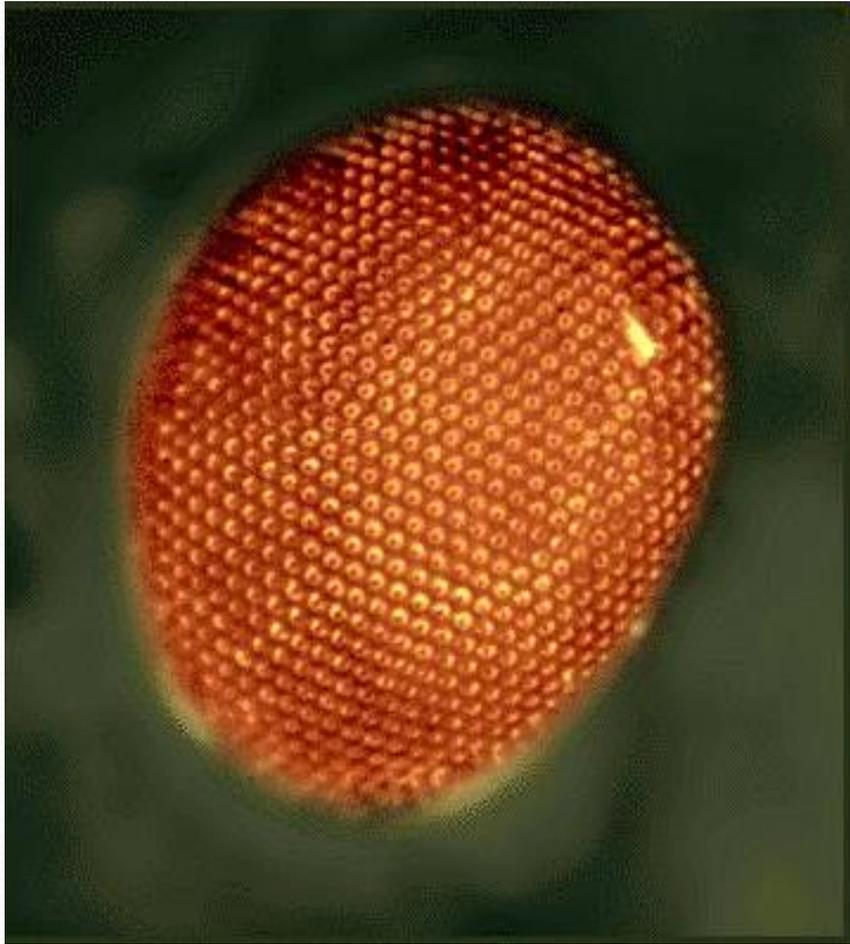
How big (small) are we  
talking about?

# *Understanding Size*



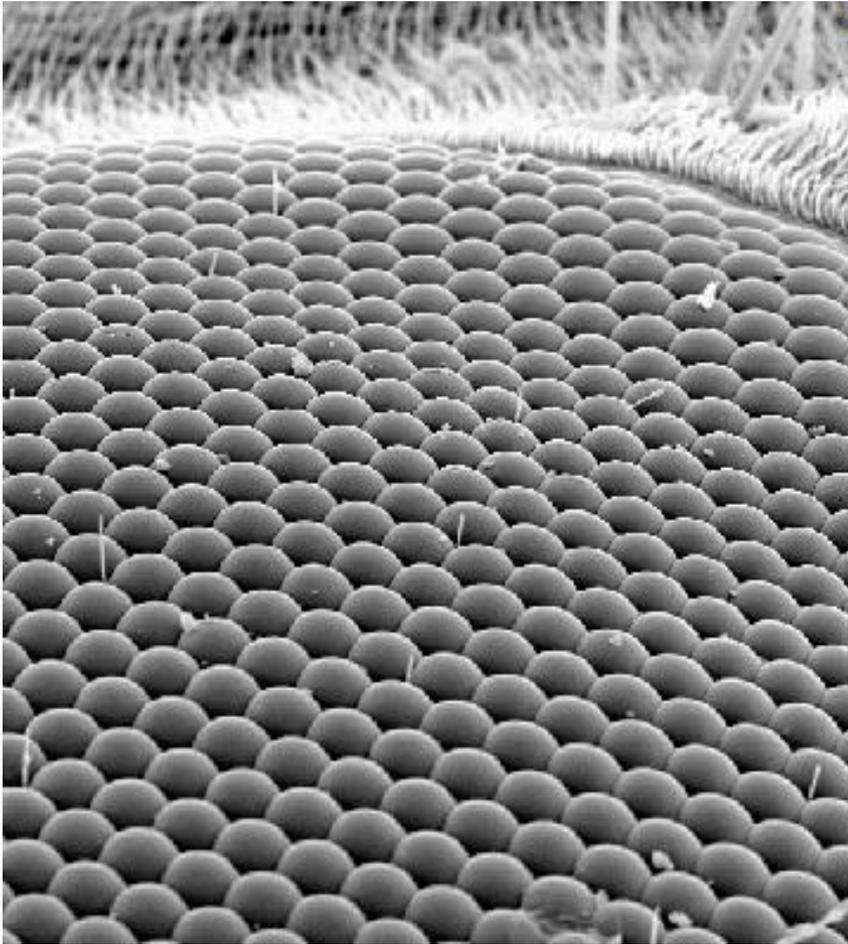
- 1 centimeter

# *Understanding Size*



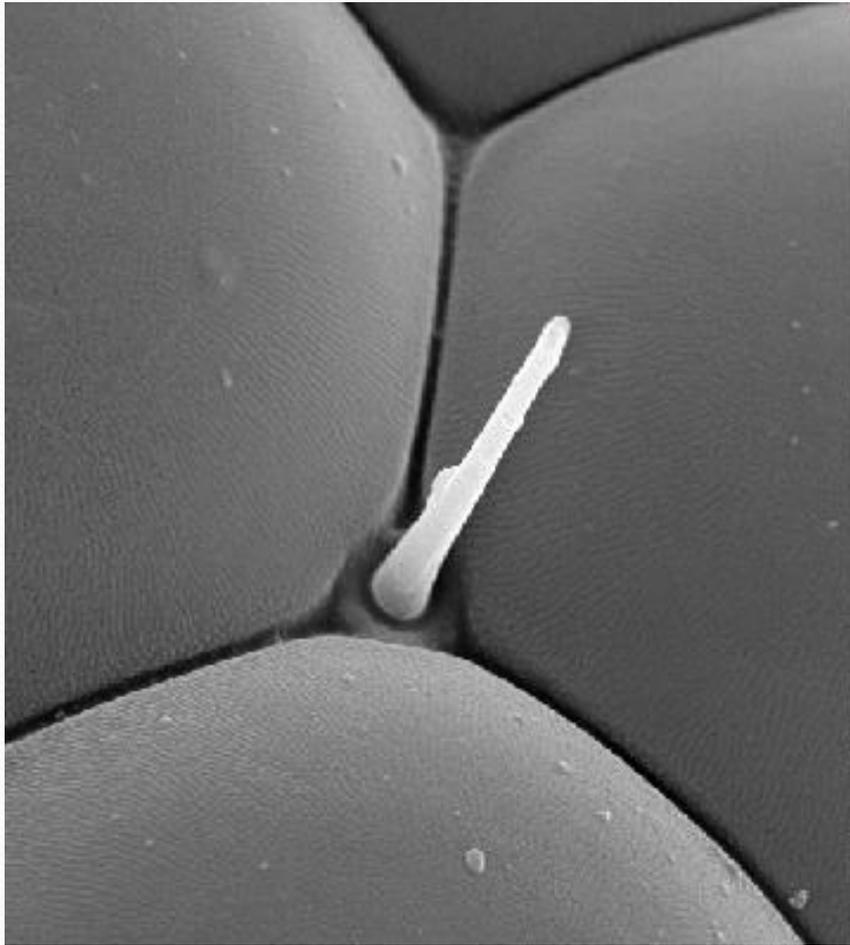
- 100 micrometers

# *Understanding Size*



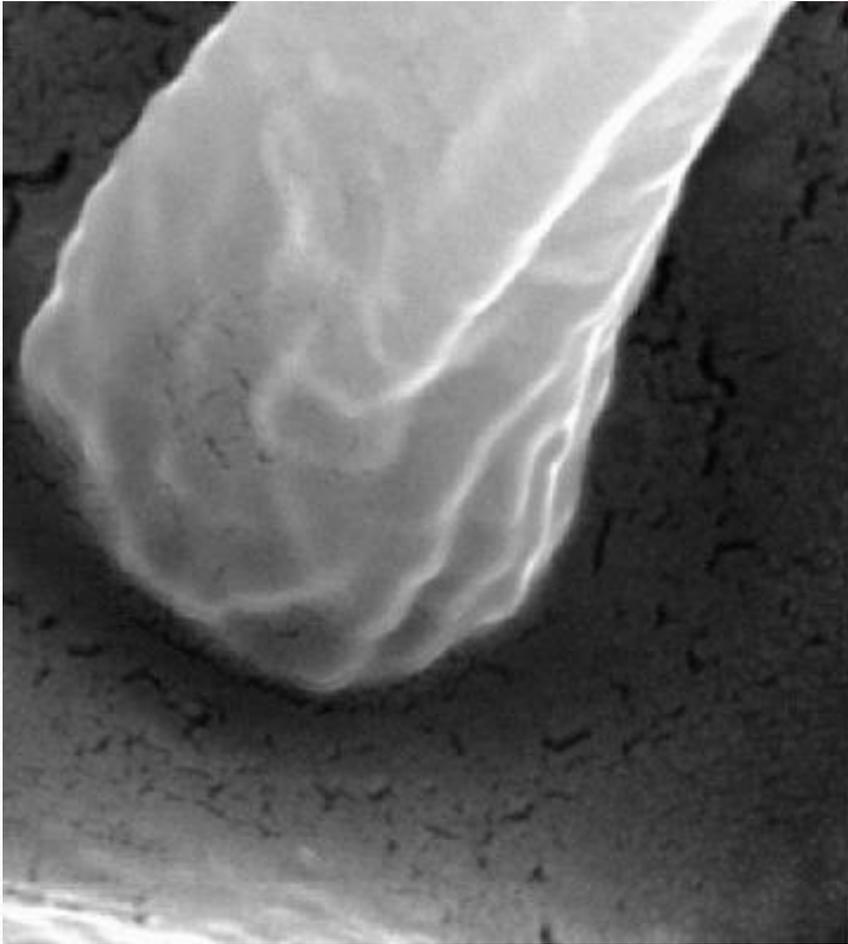
- 10 micrometers

# *Understanding Size*



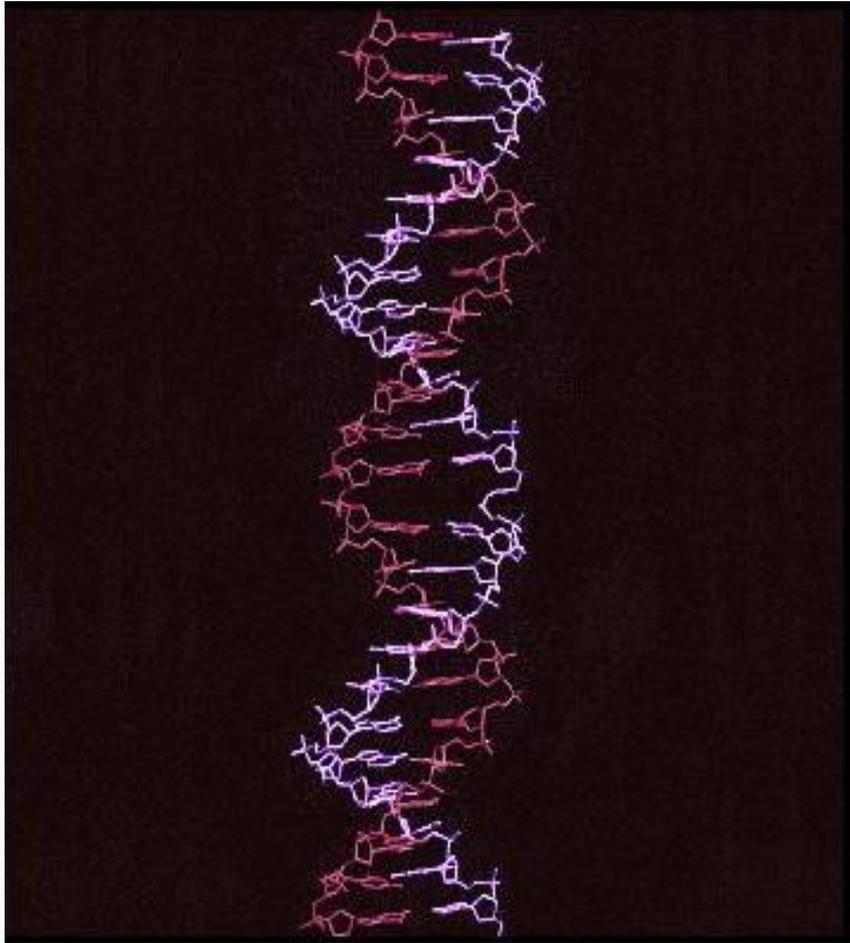
- 1 micrometer

# *Understanding Size*



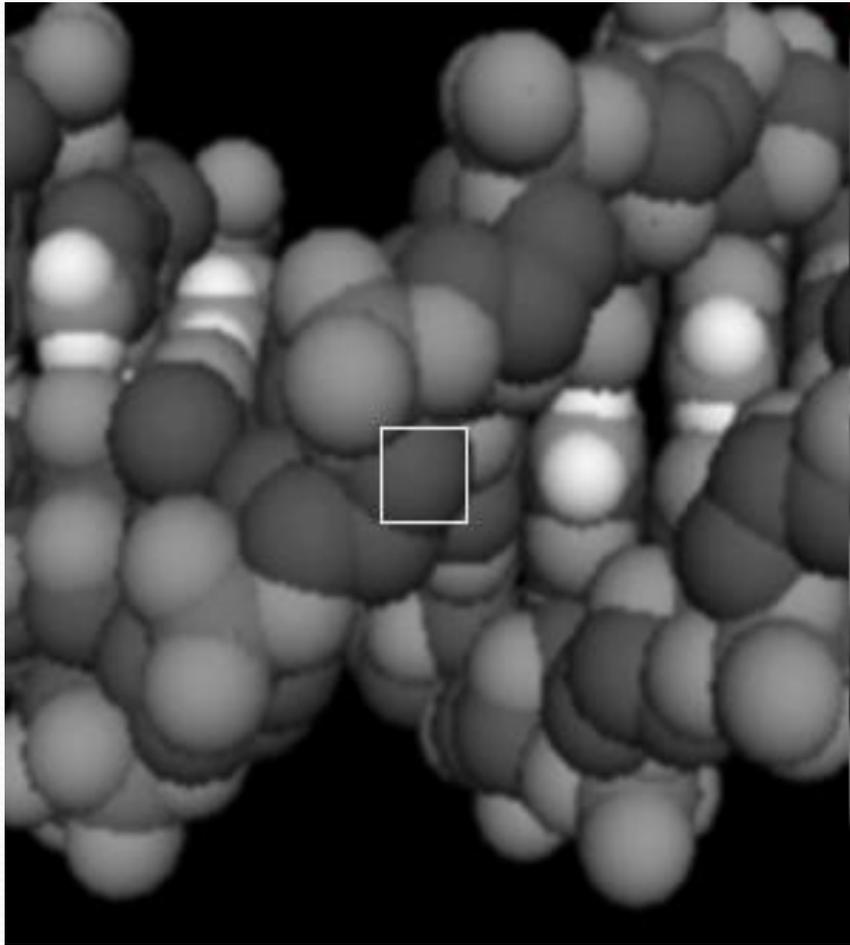
- 100 nanometers

# *Understanding Size*



- 10 nanometers

# *Understanding Size*



- 1 nanometer

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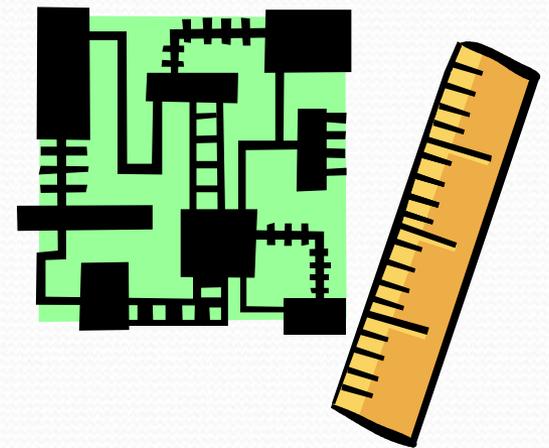
# *Properties at Scale*

“At the nanoscale, the most fundamental properties of materials and machines depend on their size in a way they don’t at any other scale”

--Mark Ratner, *Nanotechnology: A Gentle Introduction to the Next Big Idea*

Example:

As components of electronics approach the nanoscale, they no longer obey Ohms Law!



# *Understanding Effects*

Centimeter: Gravity, friction, combustion

Millimeter: Gravity, friction, combustion, electrostatic

Micrometer: Electrostatic, van der Waals, Brownian

Nanometer: Electrostatic, van der Waals, Brownian, Quantum

Angstrom: Quantum mechanics

(1/10,000,000,000 meter)

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# ***Examples and Tools***

- Nanoparticles
- Nanocomposites
- Self Assembled Structures
- MEMS and Sensors
- Material Coatings
- Carbon Nanotubes
- Nanoelectronics
- Surface characterization tools
- Atomic Force Microscope
- Nanofabrication tools
  - electron beams
  - thin film depositions
  - lithography tools
- Scanning Electron Microscope

# *Nanoparticles*



100nm

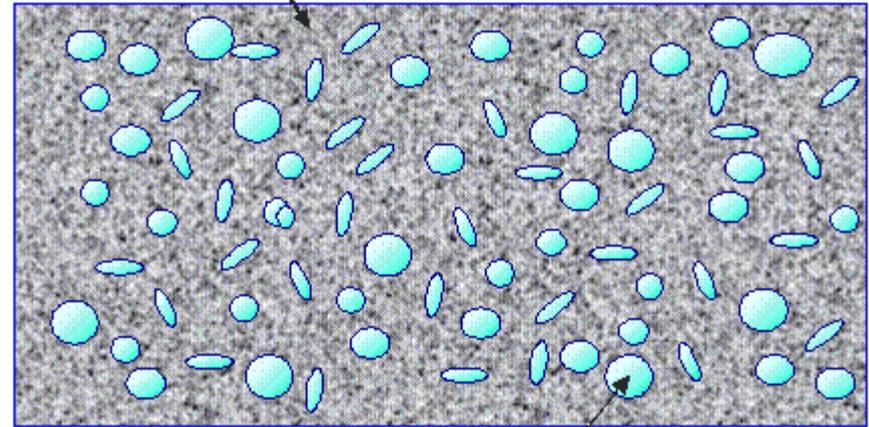
- Sun screen
- Catalysts  
(automotive)
- Corrosion  
resistance
- Solar conversion

# Nanocomposites

## Types

plastics  
foams  
aerogels  
powders  
membranes  
coatings  
films  
catalysts  
semiconductors  
magnets  
etc.

Conductive ceramic host



Nanoscale tin particles

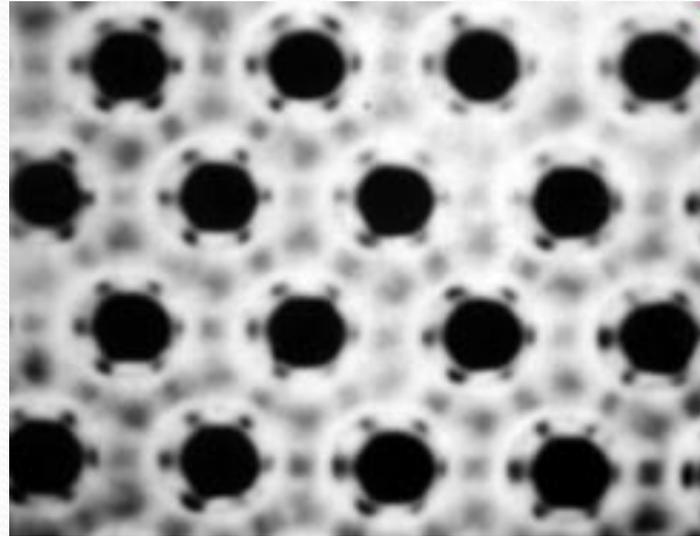
# *Self Assembly*

Crystals

Proteins

Viruses

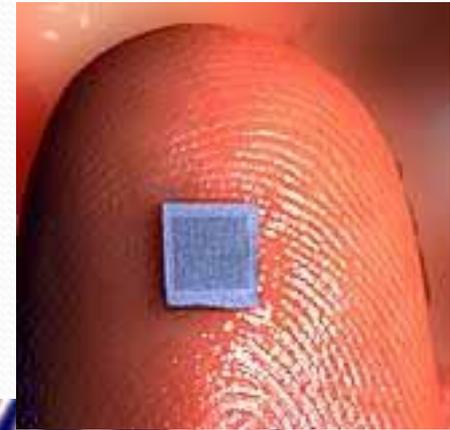
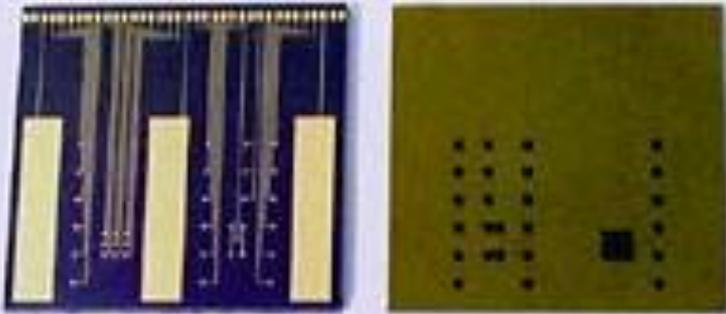
Fractals



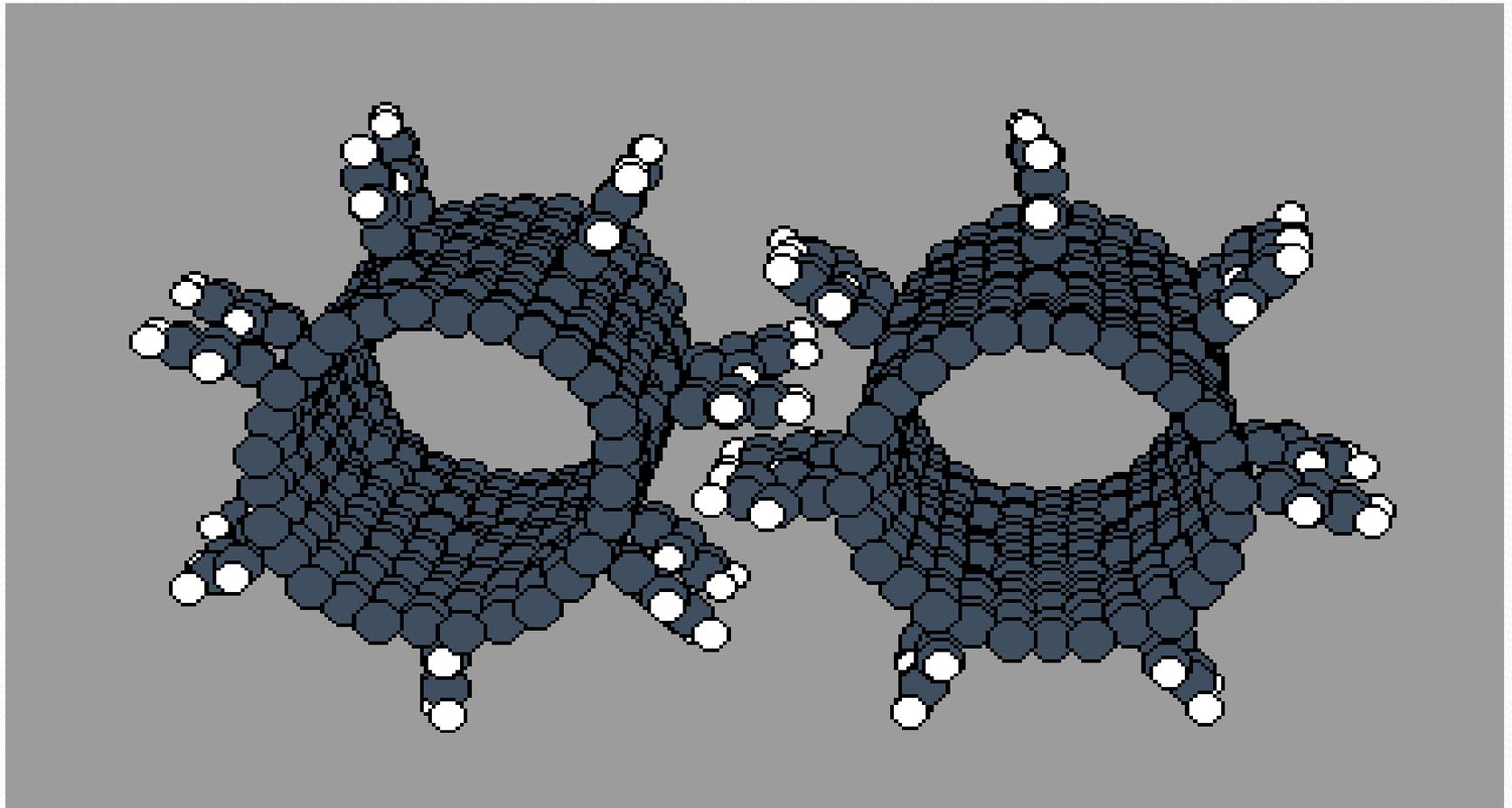
Self-assembly is a process

- Nature has harnessed it
- Nanotechnology will harness it

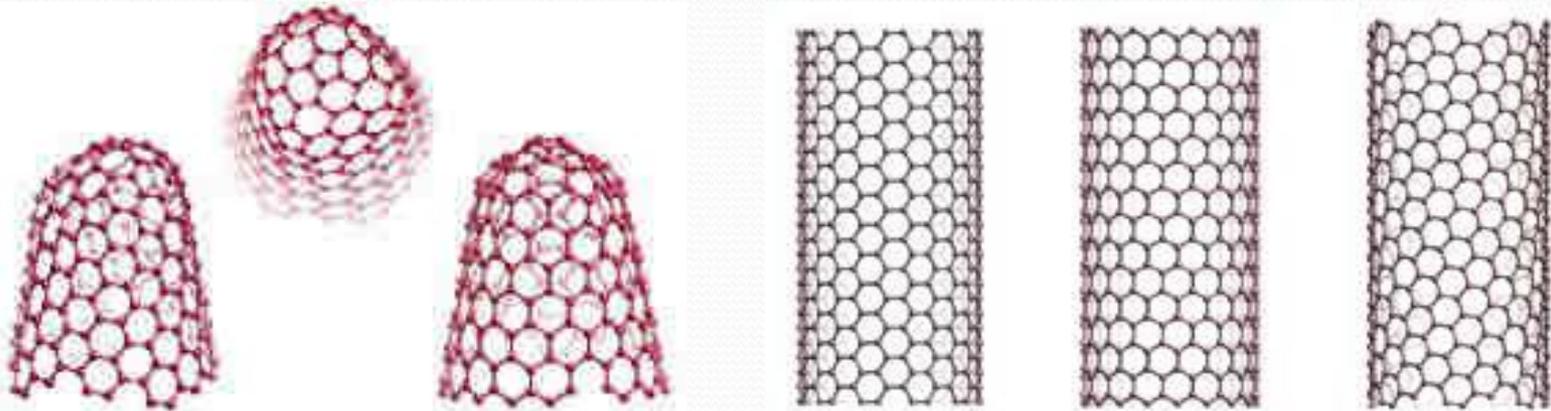
# *Druga Delivery*



# ***Carbon Nanotube Structures***

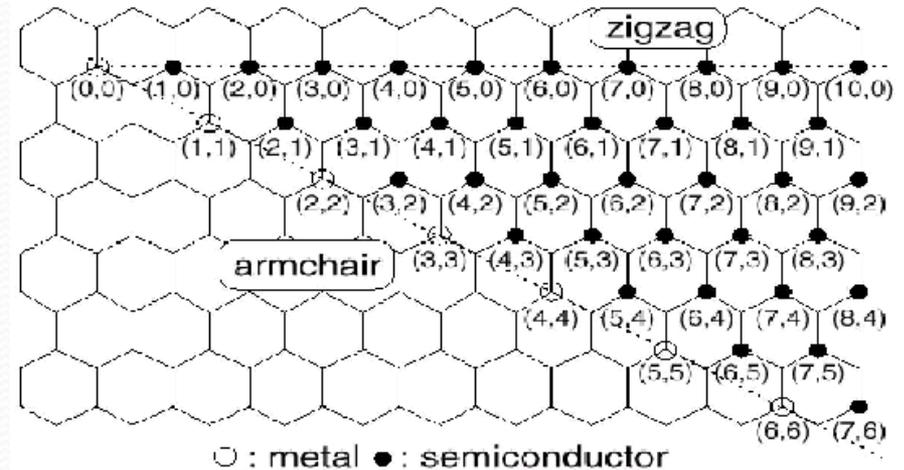
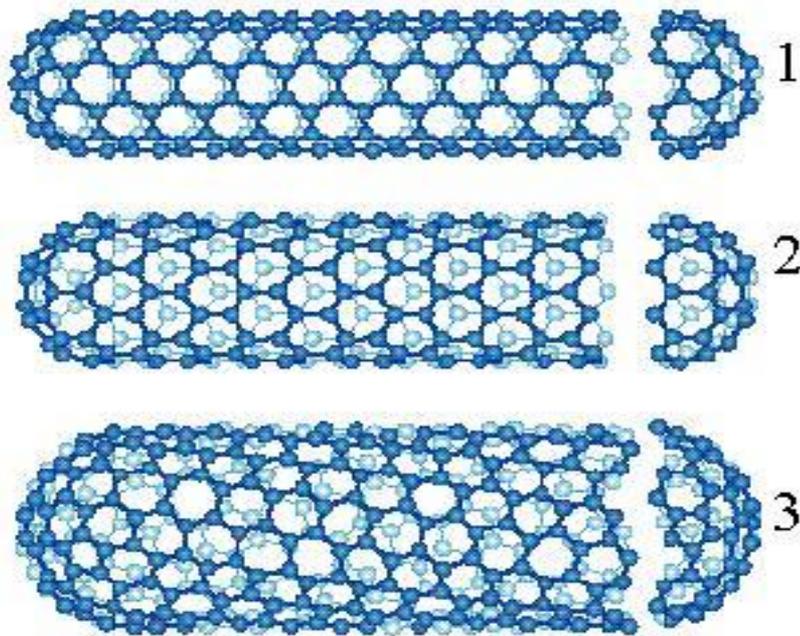


# *Nanotubes / Nanohorns*



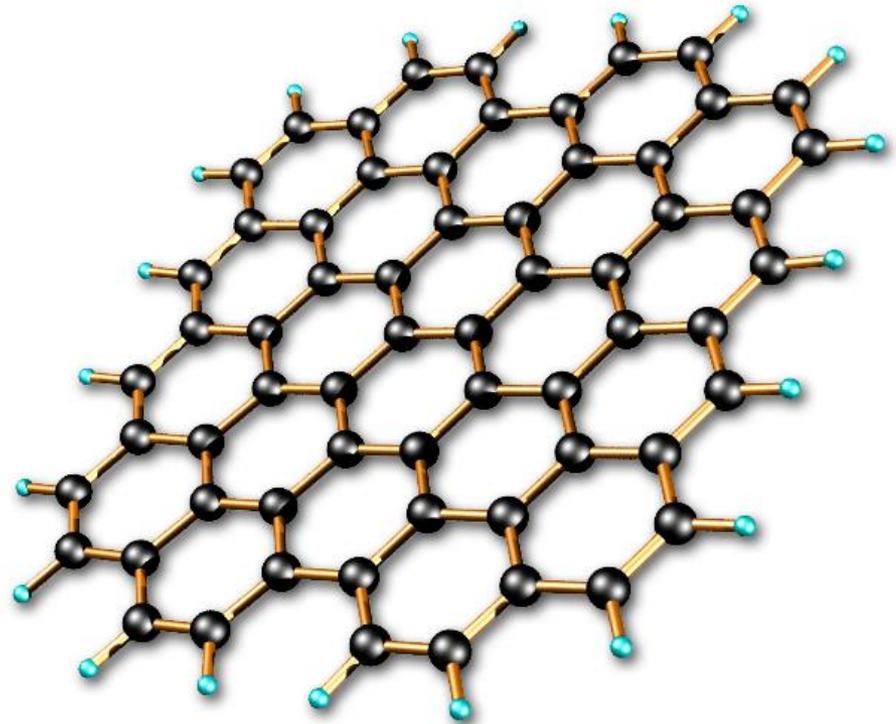
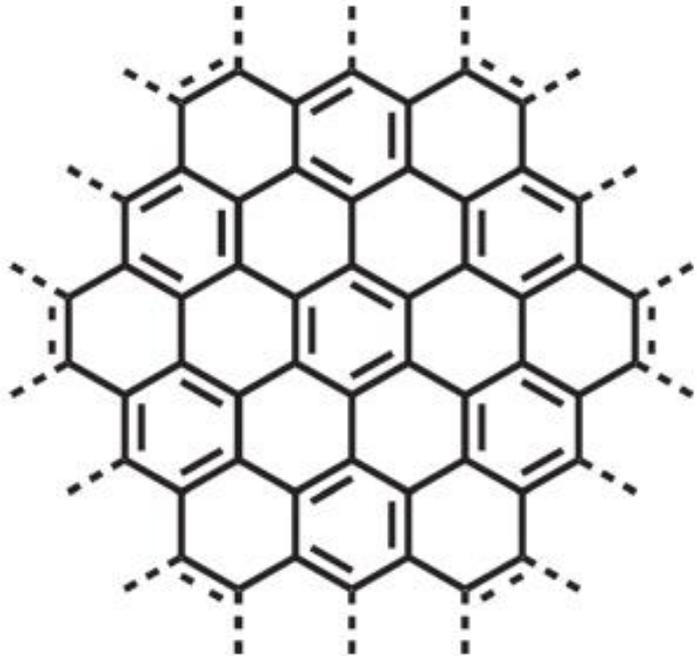
The electrical properties of nanotubes / nanohorns can change, depending on their molecular structure. The "armchair" type has the characteristics of a metal; the "zigzag" type has properties that change depending on the tube diameter—a third have the characteristics of a metal and the rest those of a semiconductor; the "spiral" type has the characteristics of a semiconductor.

# Nanotube Properties



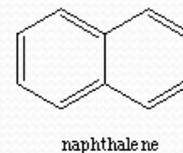
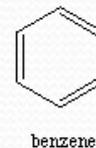
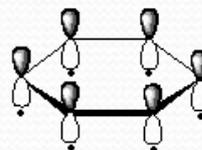
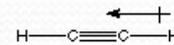
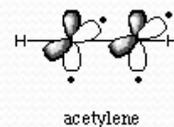
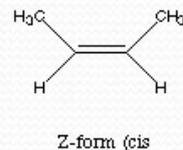
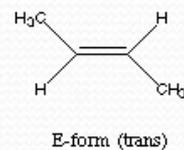
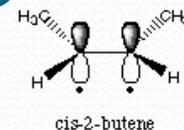
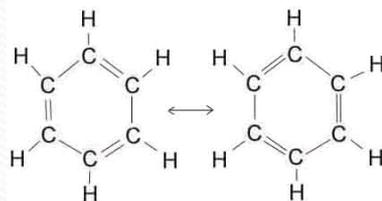
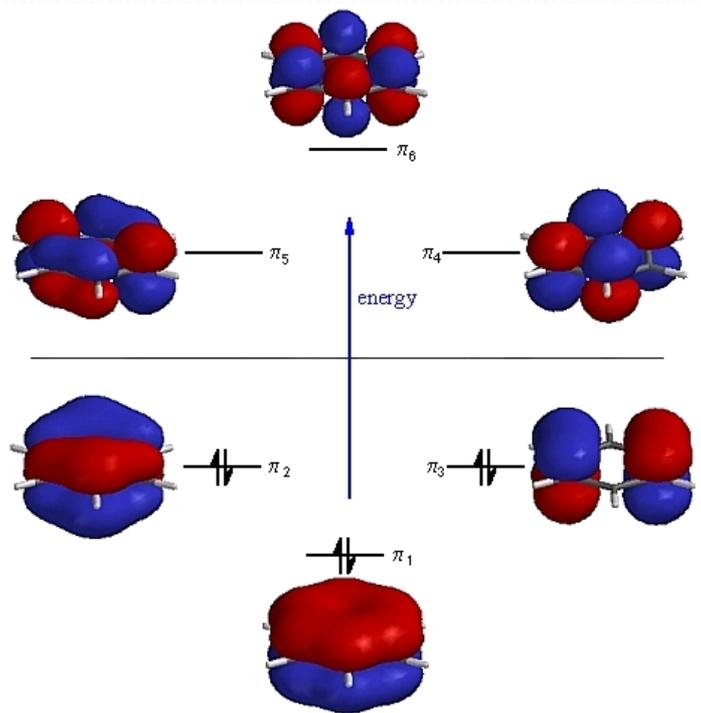
<http://nanotech-now.com/nanotube-buckyball-sites.htm>

# ***Graphene Nanostructure***

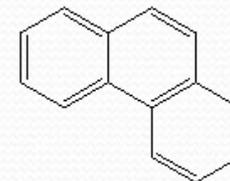


***Extended  $sp^2$  hybridized carbon and  $p-p^*$  network***

# Graphene Building Blocks

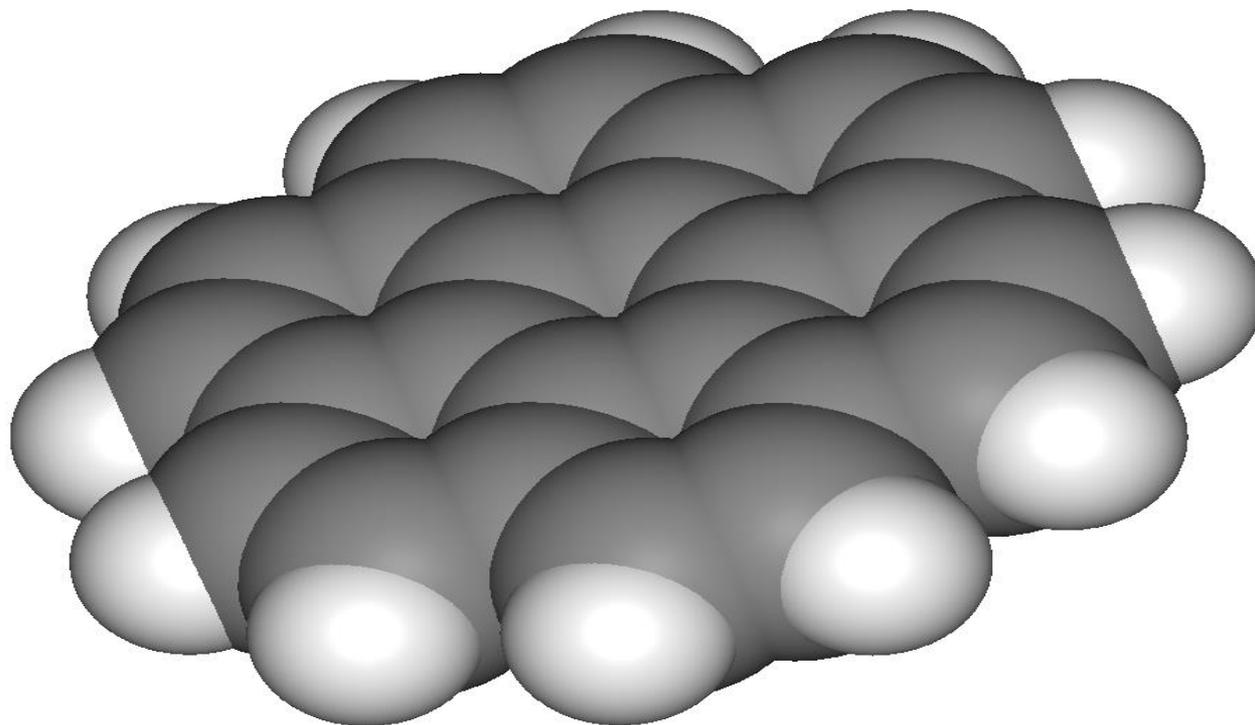


$4n + 2$   $\pi$  electrons  
Huckel number = 6



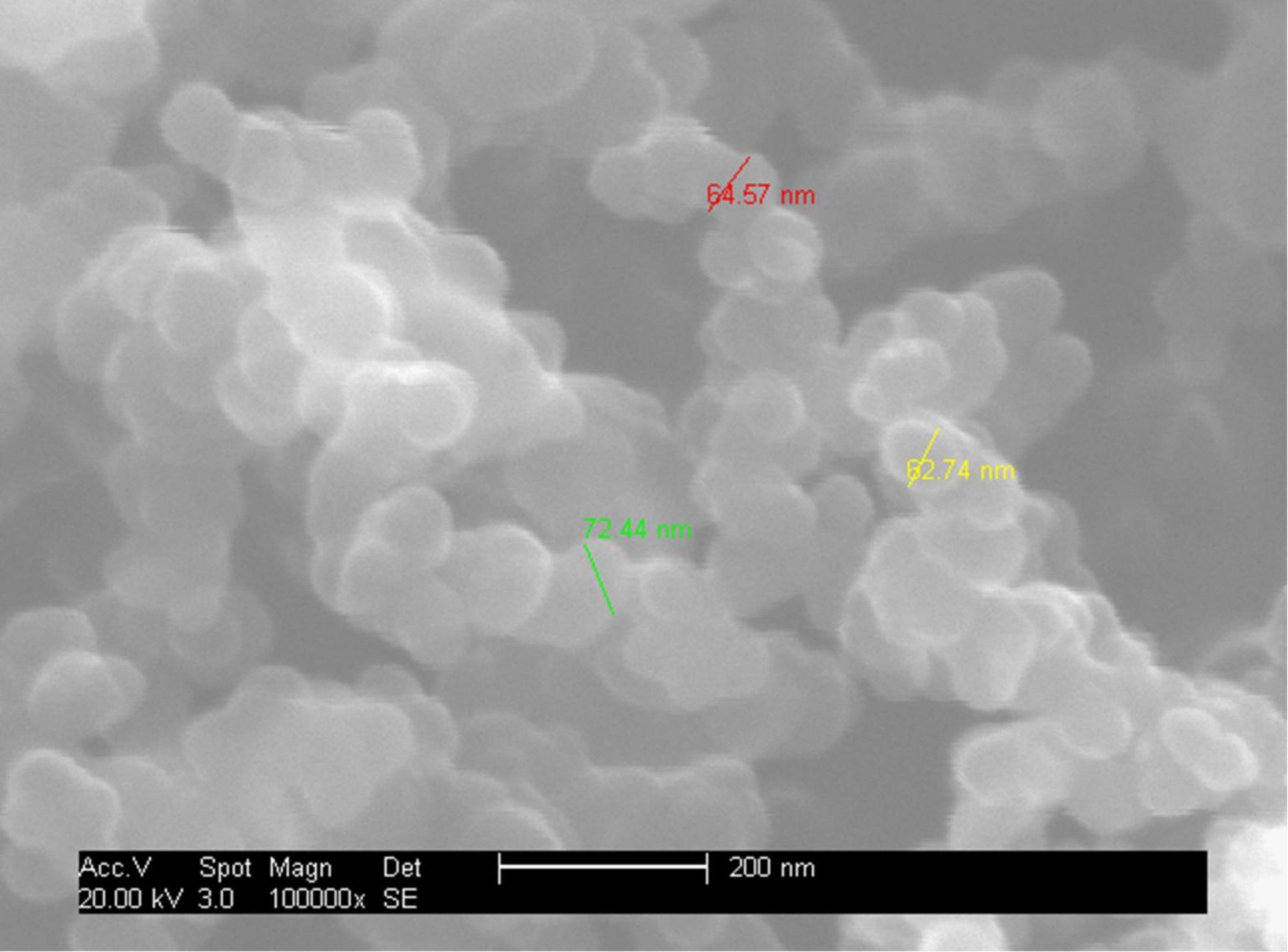
phenanthrene

# ***Coronene Ring System***



# *Nanospheres*

- Nanospheres are a novel form of carbon prepared from acetylene, or annealing of other forms of ‘precursor’ carbon
- These materials can be ‘blended’ as composites with mechanical properties
- Process tools include CVD/furnace
- Characterization tools include Raman
- Maximize  $sp^2$  bonds / graphitic nano-onion

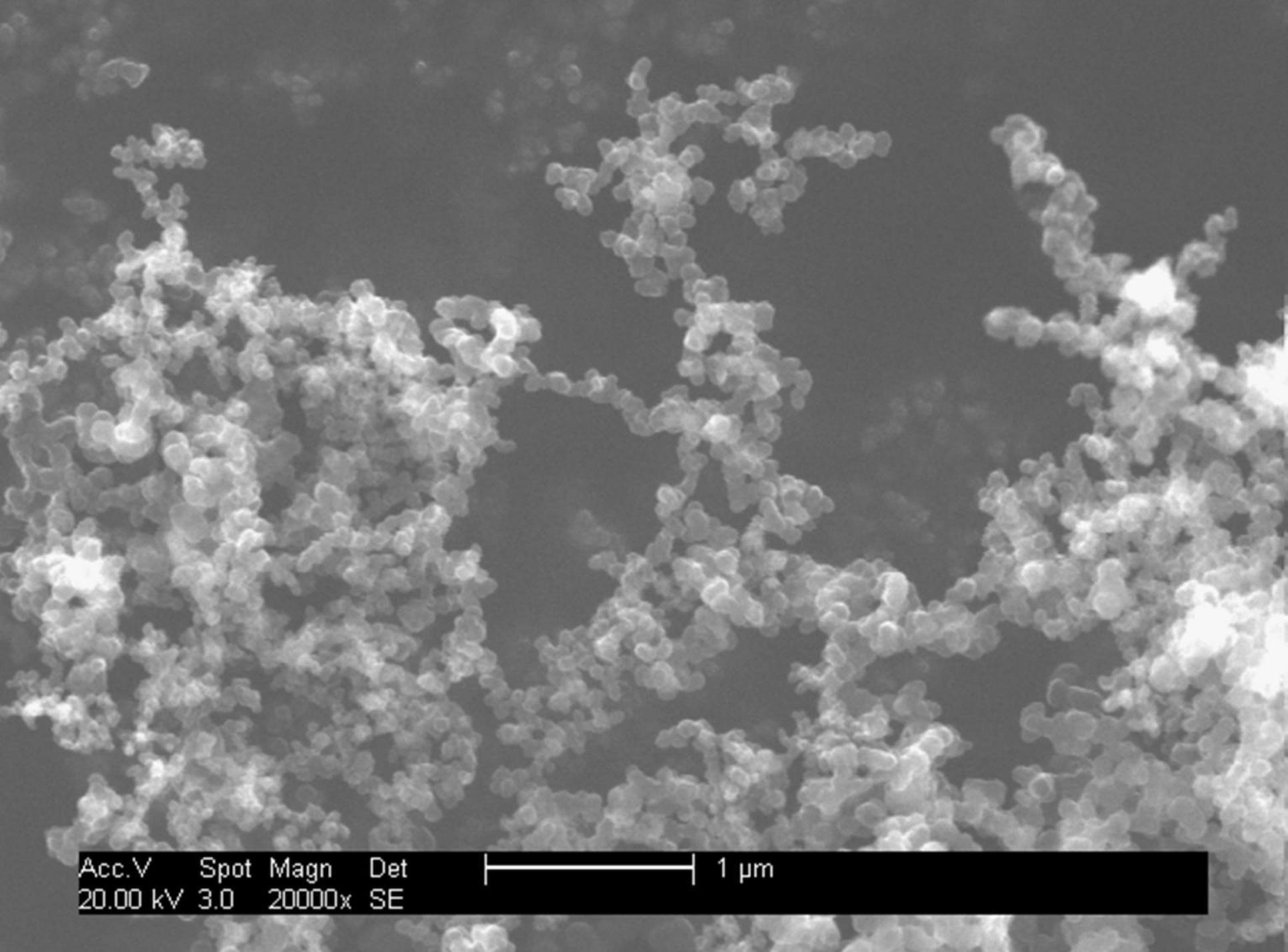


64.57 nm

62.74 nm

72.44 nm

Acc.V	Spot	Magn	Det		200 nm
20.00 kV	3.0	100000x	SE		

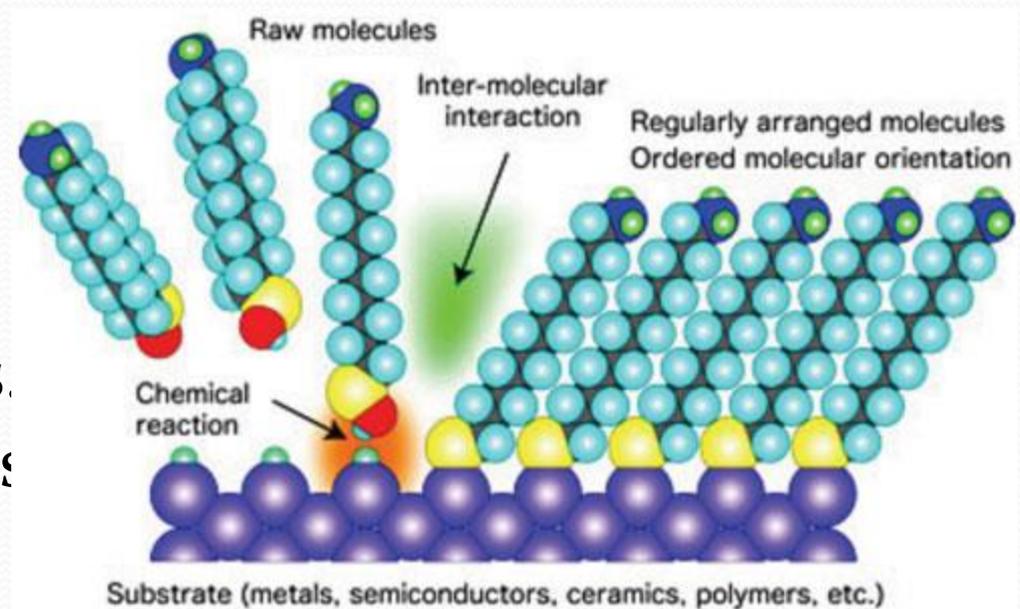


Acc.V Spot Magn Det  
20.00 kV 3.0 20000x SE

1  $\mu$ m

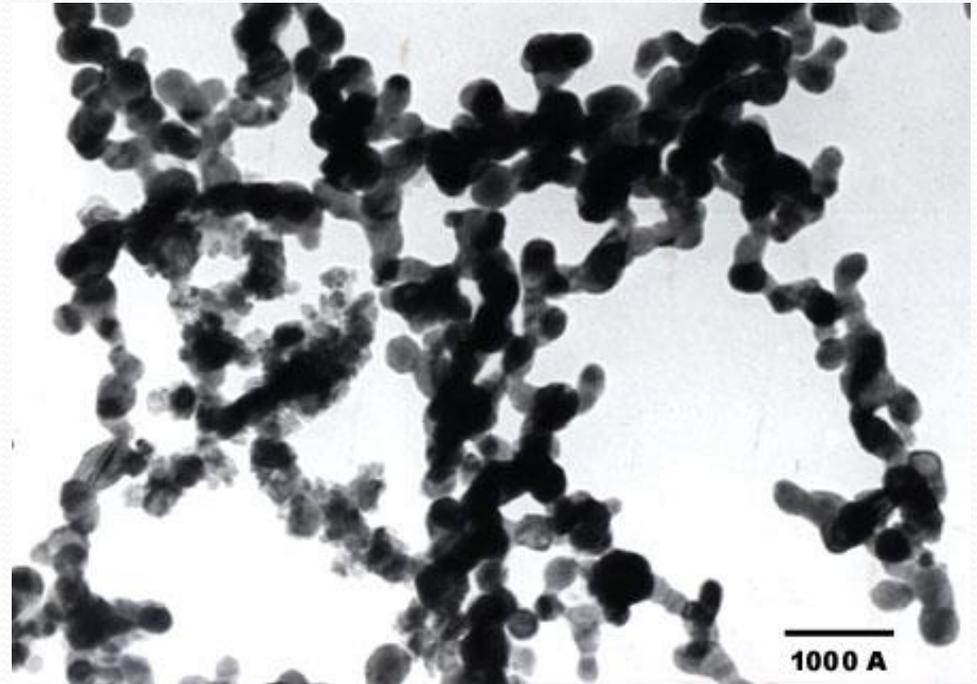
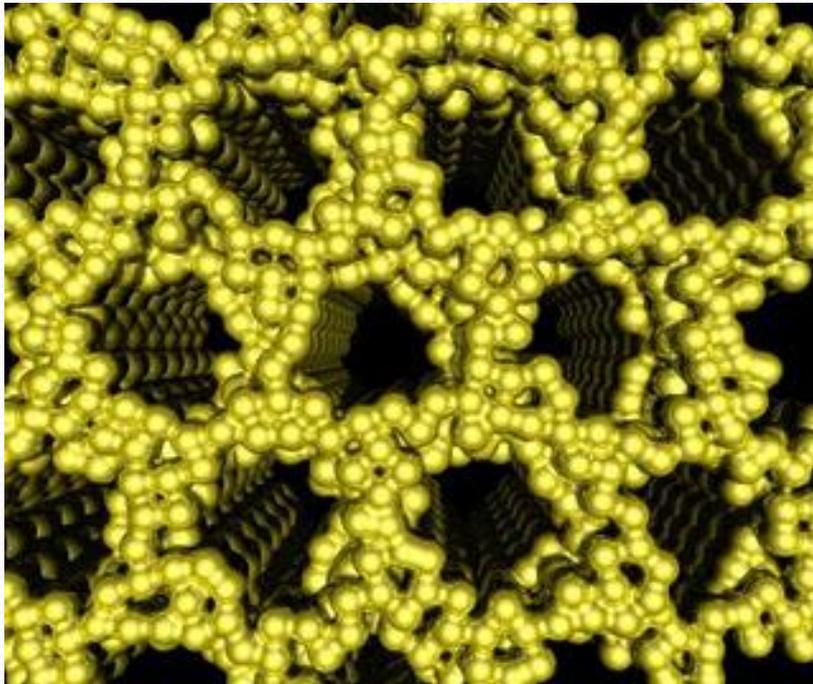
# Self Assembly

- Under specific conditions, some materials can spontaneously assemble into organized structures. This process provides a useful means for manipulating matter at the nanoscale.

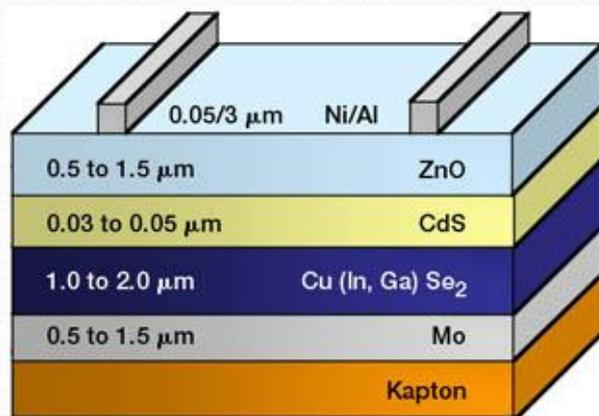


<http://nimet.ufl.edu/nanomed.asp>

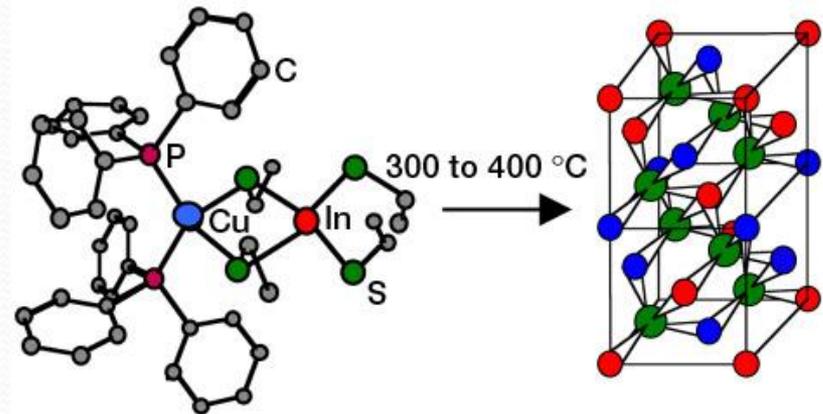
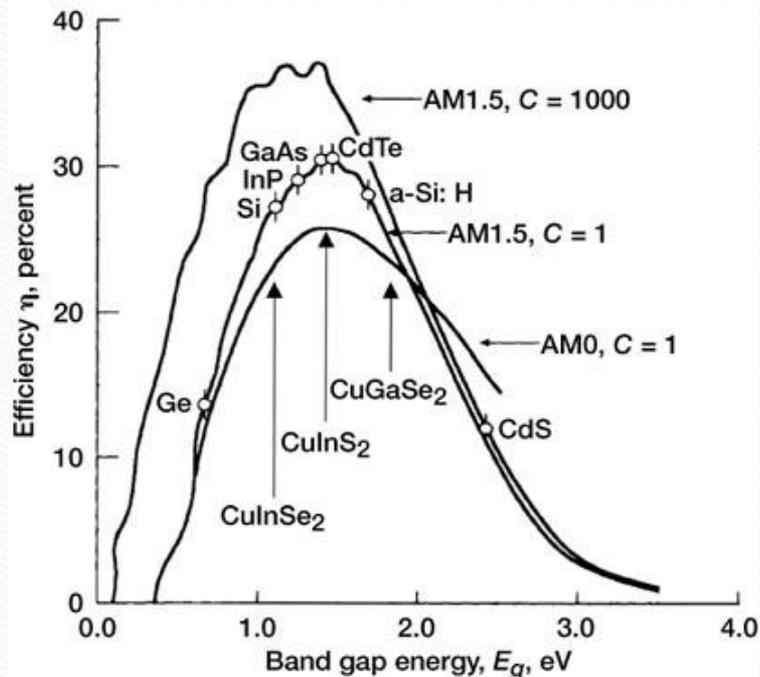
# *Nanometal Structures*



# *Thin Film Solar on Kapton®*



# Thin Film Engineering



Left image: Predicted efficiency versus bandgap for thin-film photovoltaic materials for solar spectra in space (AM0) and on the surface of the Earth (AM1.5) at 300 K.  
Right image: Decomposition of single-source precursor to produce  $\text{CuInS}_2$

<http://www.grc.nasa.gov/WWW/RT/RT1999/5000/5410hepp.html>

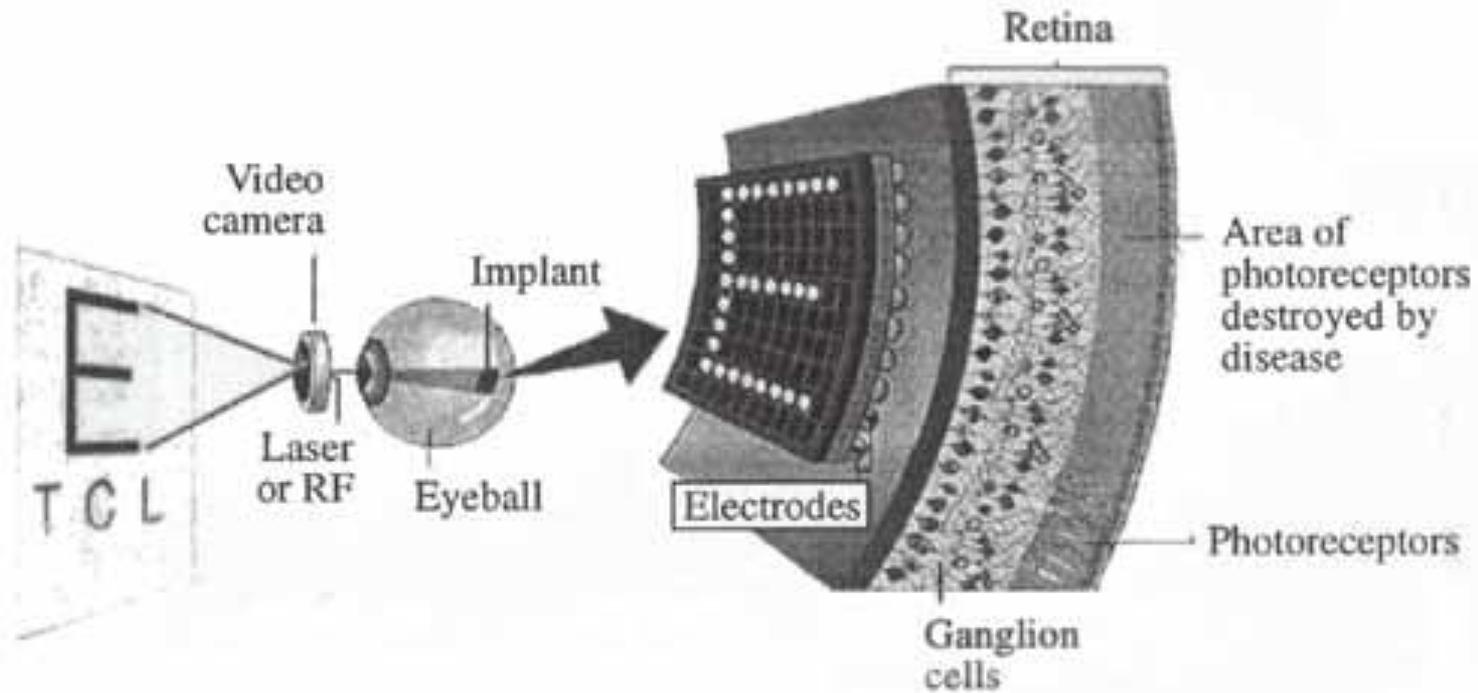
# ***Implantable Sensors***

CardioMEMS microchip that could be implanted in the body to transmit information about blood flow and pressure wirelessly.



# Sensory Aids

## Retina Implants



# *Tools and Instruments*

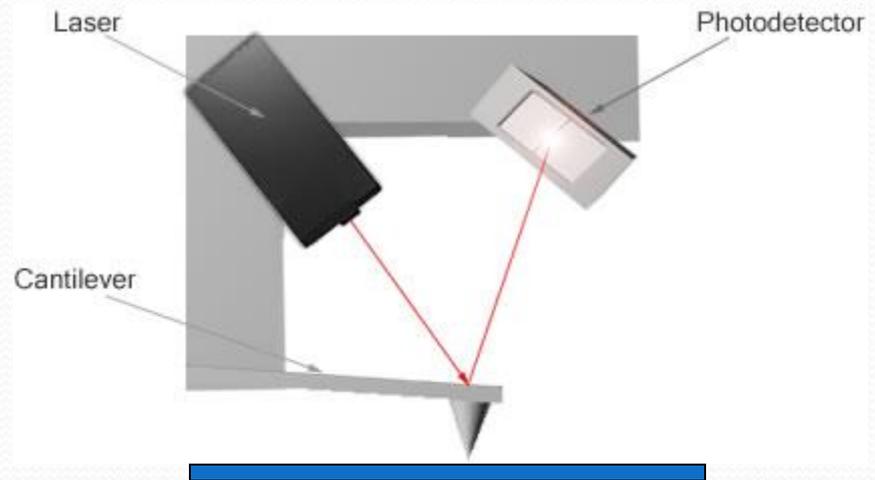
- Modeling tools
- Process tools
- Characterization measurement tools
- Fabrication tools



Brooklyn College has a multimode AFM manufactured by Digital Instruments, Inc (Veeco Instrument.). The Digital Instruments Multimode is the highest resolution, commercially available scanning probe microscope (SPM). It is designed for atomic-scale resolution imaging of material surfaces. It can be used for different materials of interest such as metals, insulators, ceramics, polymers, and biological samples. Sample preparation is minimal; however, sample size is limited to approximately 1 square centimeter and samples must be low profile. <http://userhome.brooklyn.cuny.edu/mlnakarmi/facility/AFM.html>

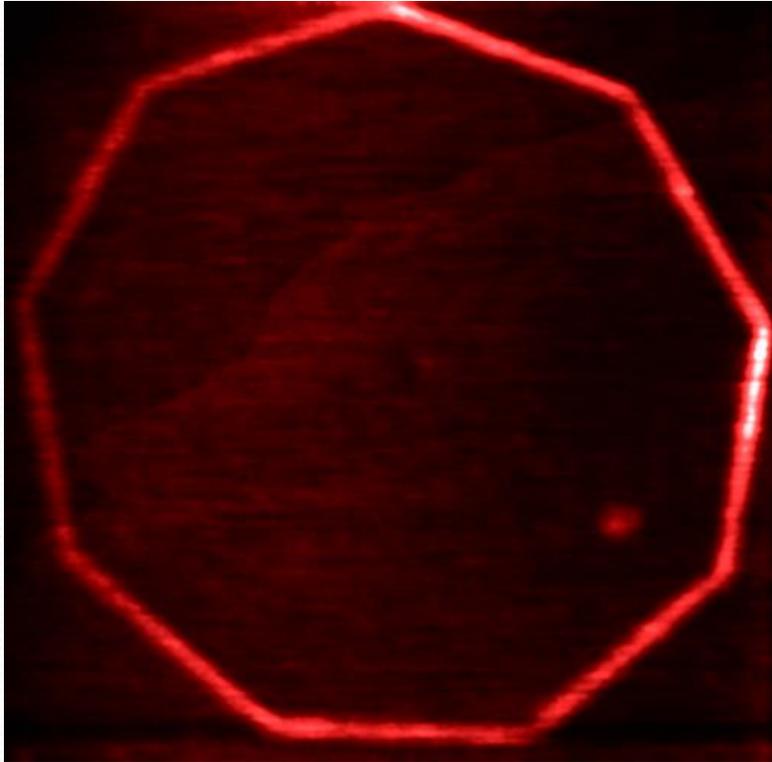
# Atomic Force Microscopy

- Uses a sharp probe to magnify surface features
- extremely high magnifications, up to 1,000,000X
- 3D images
- Also used to modify surfaces
  - Lithography (creating features)
  - Storage devices

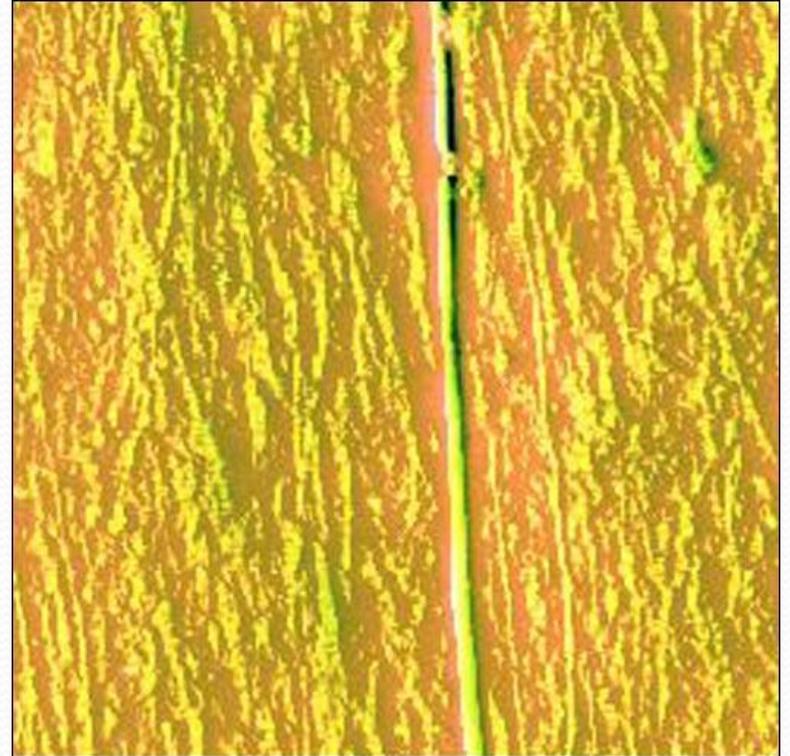


The light lever sensor uses a laser beam to monitor the deflection of the cantilever. When the cantilever moves up and down, the light beam moves across the surface of the photo-detector.

# ***AFM Images***



AFM lithography, 10x10um



10x10um Steel, polishing marks

# Modeling Tools

## What is Nanostructure Modeling?

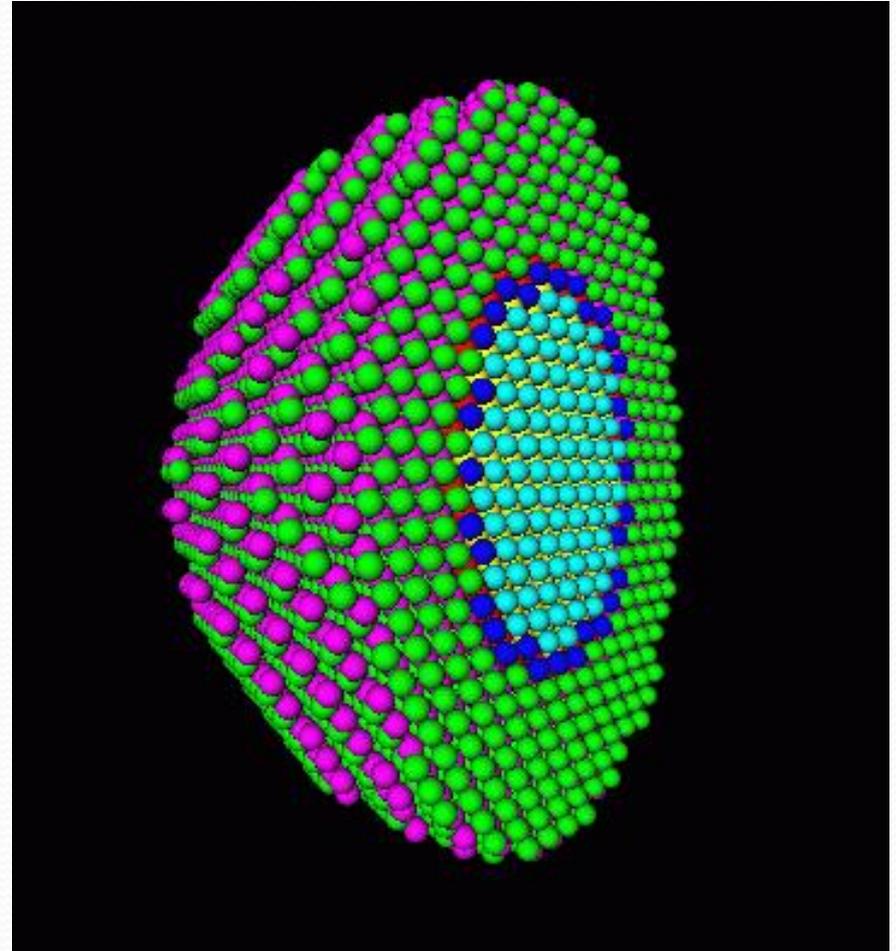
Nanostructure modeling is the computation of the positions and orbitals of atoms in arbitrary nanostructures.

## Why is Nanostructure Modeling Important?

Accurate atomic-scale quantum theory of nanostructures and nanosystems fabricated from nanostructures enables precision metrology of these nanosystems and provides the predictive, precision modeling tools needed for engineering these systems for applications including advanced semiconductor lasers and detectors, single photon sources and detectors, biosensors, and nanoarchitectures for quantum coherent technologies such as quantum computing. The tight-binding model based upon the Linear Combination of Atomic Orbitals (LCAO) method provides an accurate atomistic theory for nanostructures.

## Why Visualize Nanostructures?

The visualizations are studied interactively in the NIST immersive environment. This provides a detailed view of the structures and the atomic scale variation of the calculated nanostructure properties.



<http://math.nist.gov/mcsd/savg/vis/nano/index.html>

# NanoViz Modeling Tool

The screenshot displays the NanoViz Modeling Tool interface. The central 3D view shows a pyramid-shaped structure composed of numerous small spheres and larger teardrop-shaped objects, colored in blue, green, yellow, and pink. The structure is centered at the origin of a 3D coordinate system.

**translation**

X: [0] Y: [0] Z: [1.588]

**rotation**

H: [2.2] P: [0] R: [0]

**scale**

X: [6.542] Y: [6.594] Z: [2.116]

uniform scaling

RESET

**orbitalFilters**

exclude less than: [0]

exclude greater than: [0.347]

min: 0.000000 max: 0.346410

orbital magnification: [3.3884]

uniform size [reset]

**2794 points selected pyramid centered at**

0.000000, 0.000000, 1.588000  
with peak at  
0.000000, 0.000000, 5.253019  
and base at  
6.284049, 6.840272, -0.528000  
-6.790307, 6.338006, -0.528000  
-6.284049, -6.840272, -0.528000  
6.790307, -6.338006, -0.528000

**shapeSelection**

object:

cube  tetrahedron  
 sphere  pyramid

wireframe  translucent

show data:

inside  outside  shell

[50] % thickness

**legend\_nano**

S	P	Atom
■	■	- - InAs
■	■	+ + InAs
■	■	+ + InAs
■	■	- - GaAs
■	■	+ + GaAs
■	■	+ + GaAs
■	■	+ + GaAs

**orbitalWeights**

s+	0.401969	s-	0.133823
px+	0.014778	px-	0.005005
py+	0.014969	py-	0.005069
pz+	0.020361	pz-	0.006861
ss+	0.001511	ss-	0.000503
sum 0.604901			

alphas  ignore shapes  grab

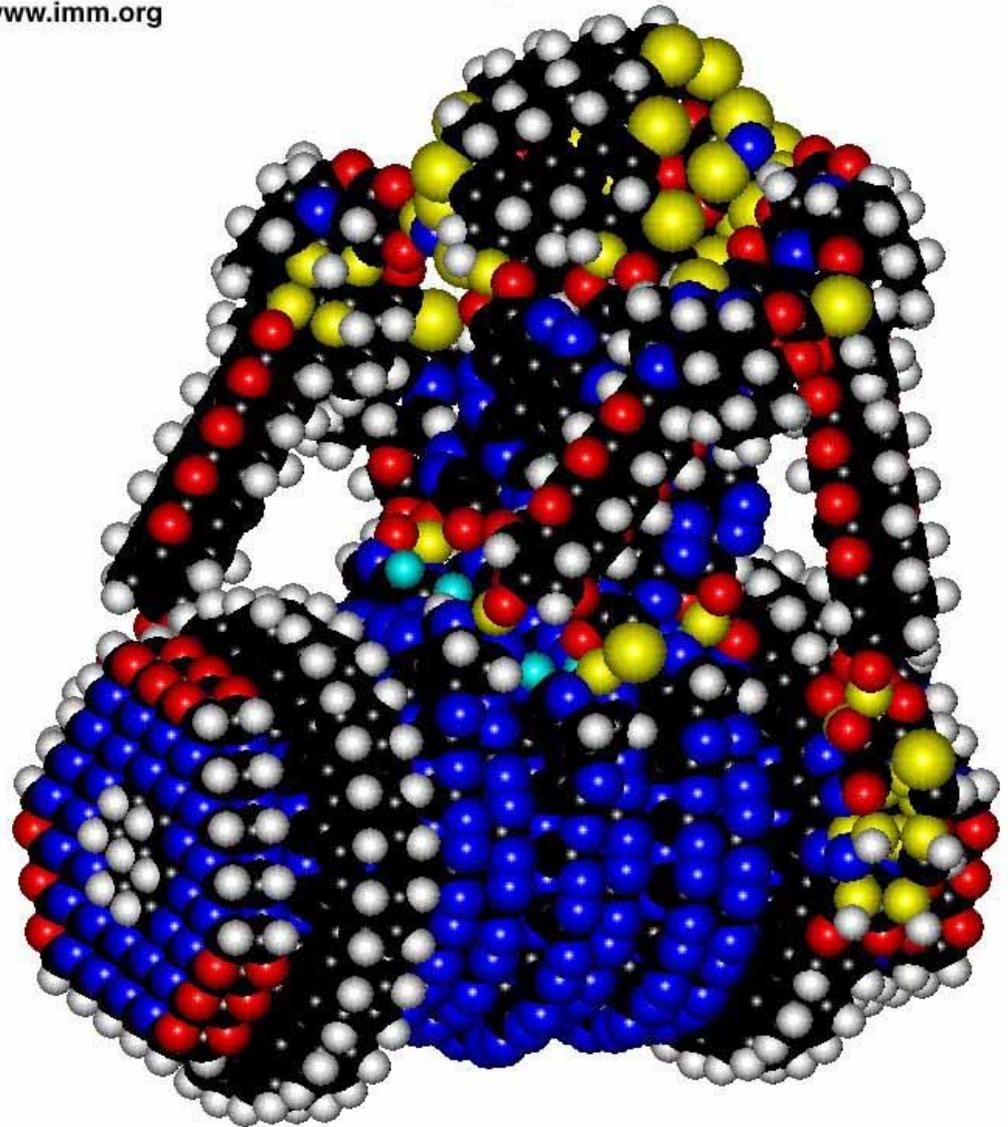
# Technology and Society

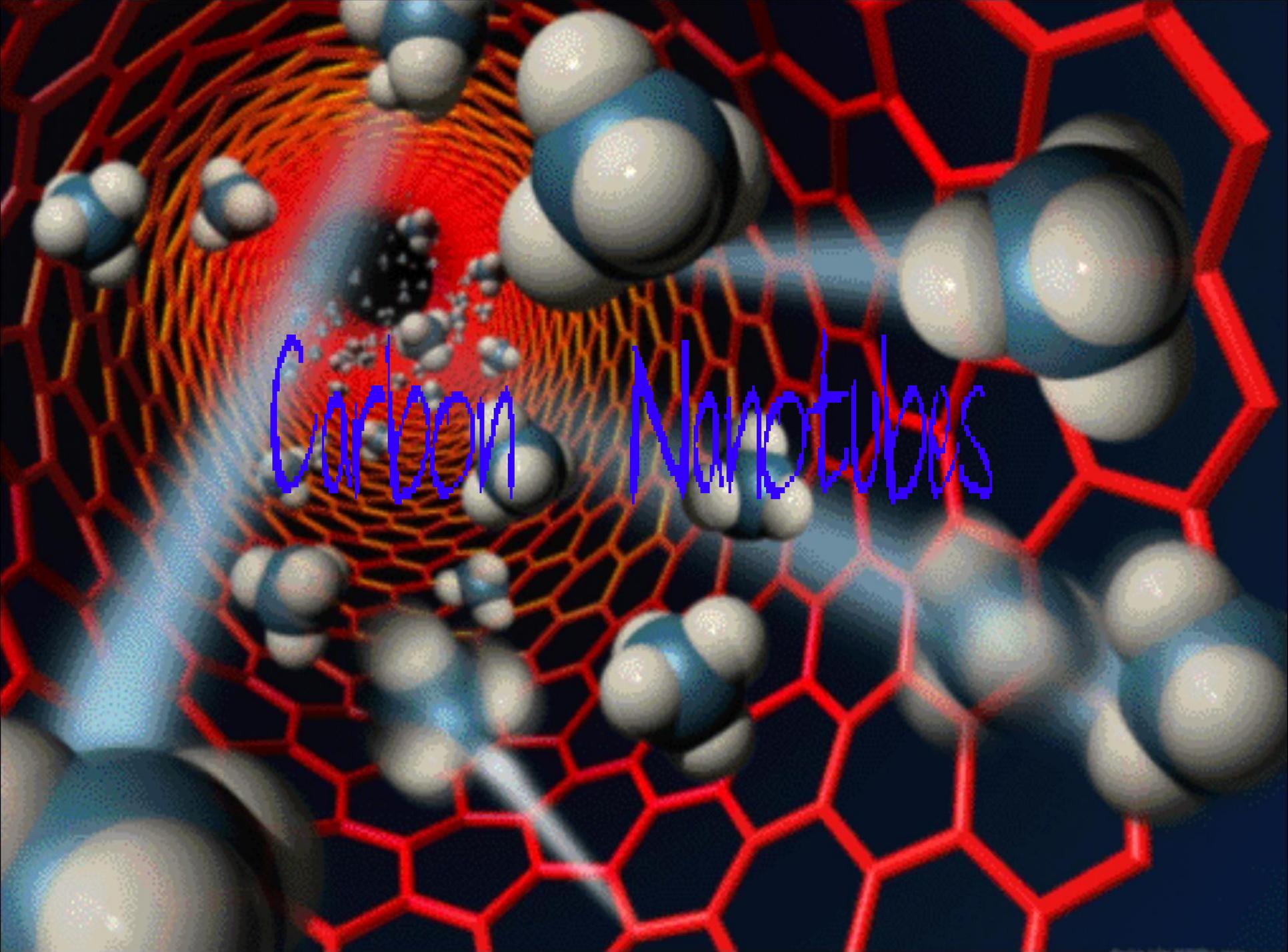
© Institute for Molecular Manufacturing  
www.imm.org

Nanosafety – assemblers – warfare. Foresight Institute's grand challenge problems:

1. Energy
2. Food
3. Water
4. Computation
5. Nanomedicine

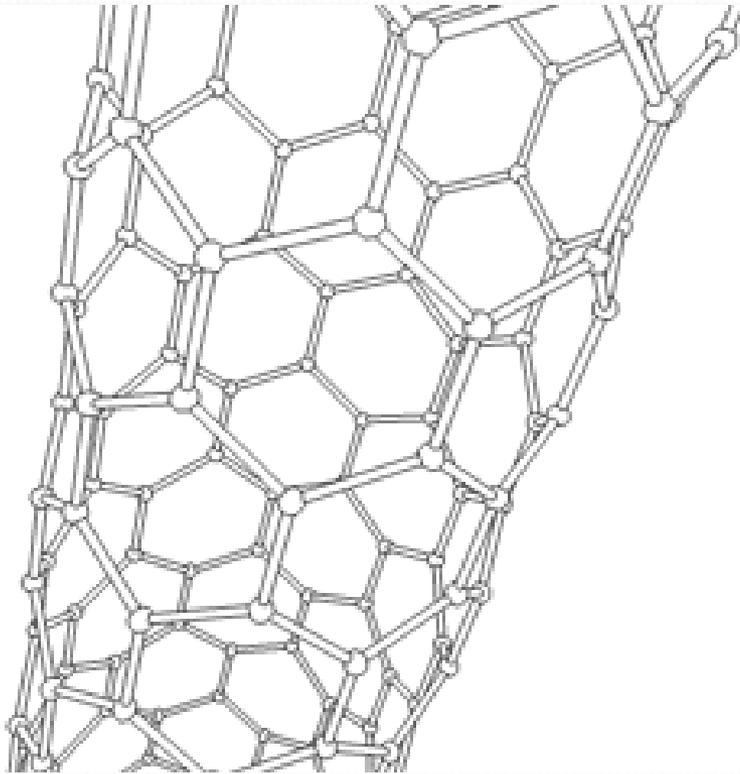
What are the safeguards for nanotechnology, and who is watching / oversight to prevent unsafe testing, manufacturing, and/or use of nanomaterials?





# Carbon Nanotubes

# What are Carbon Nanotubes?



Carbon nanotubes are hexagonally shaped arrangements of carbon atoms that have been rolled into tubes. These tiny straw-like cylinders of pure carbon have useful electrical properties. They have already been used to make tiny transistors and one-dimensional copper wire.

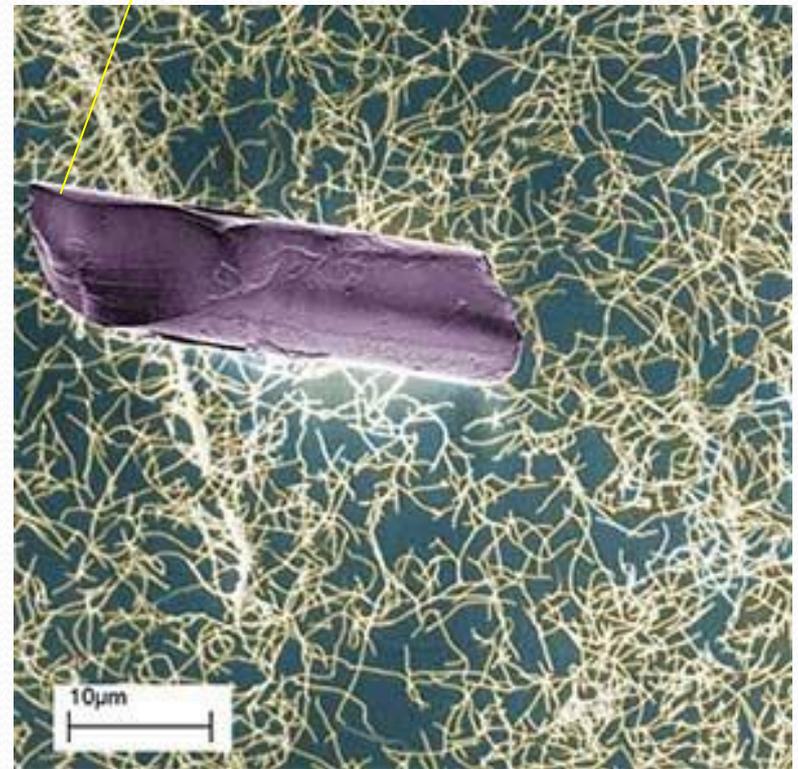


Nanotubes have been constructed with length- to-diameter ratio of up to 132,000,000:1,[1] which is significantly larger than any other material. These cylindrical carbon molecules have novel properties that make them potentially useful in many applications. They exhibit extraordinary strength and unique electrical properties, and are efficient thermal

Nanotubes are members of the fullerene structural family, which also includes the spherical buckyballs. The ends of a nanotube might be capped with a hemisphere of the buckyball structure. Their name is derived from their size, since the diameter of a nanotube is on the order of a few nanometers (approximately 1/50,000th of the width of a human hair), while they can be up to 18 centimeters in length (as of 2010).

Nanotubes are categorized as single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs).

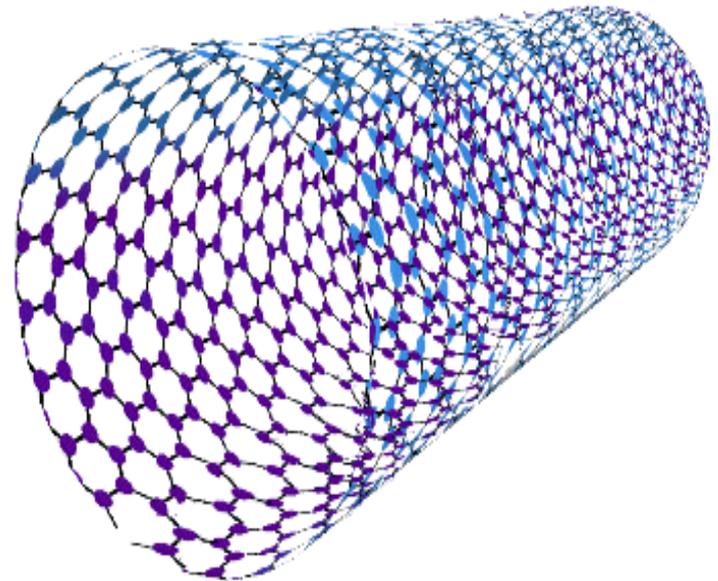
Human hair fragment (the purplish thing) on top of a network of single-walled carbon nanotubes



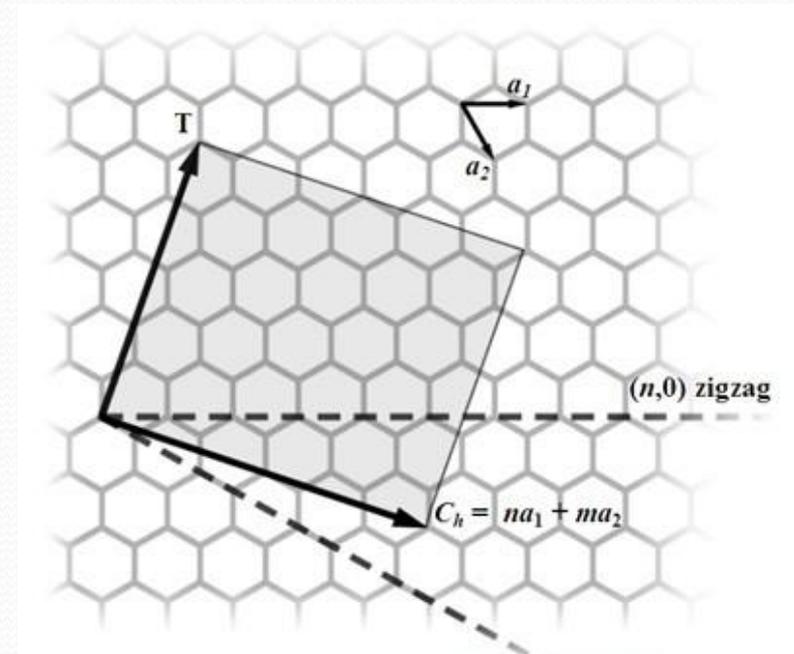
# Single-walled

- Most single-walled nanotubes (SWNT) have a diameter of close to 1 nanometer, with a tube length that can be many millions of times longer. The structure of a SWNT can be conceptualized by wrapping a one-atom-thick layer of graphite called graphene into a seamless cylinder.

From Computer Desktop Encyclopedia  
© 2007 The Computer Language Company Inc.

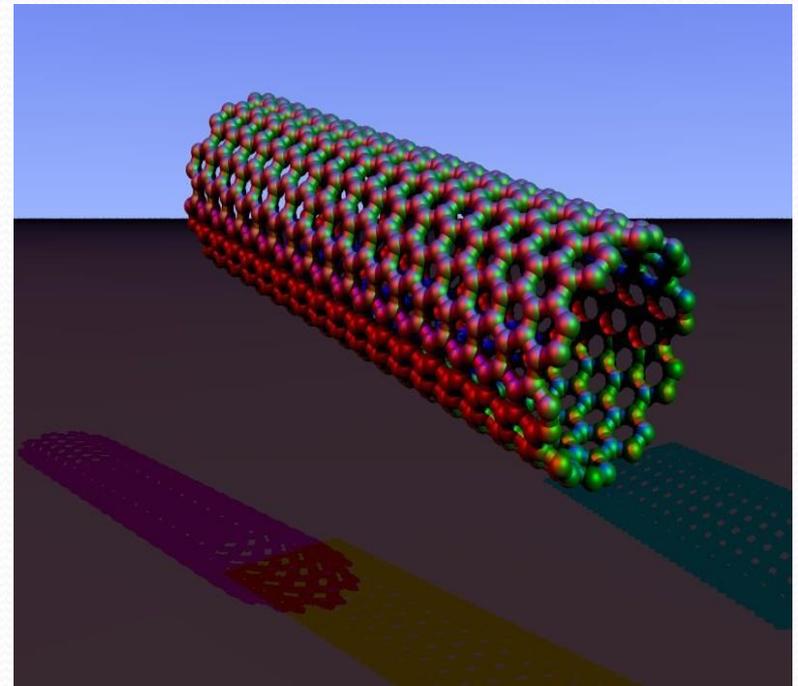


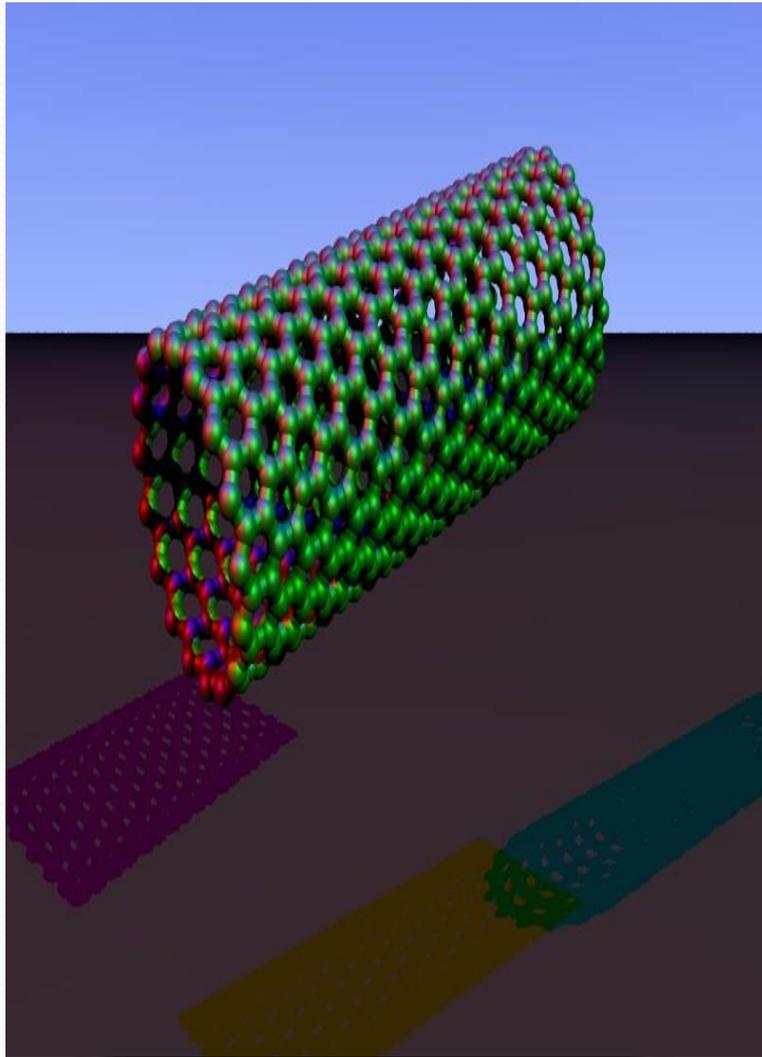
- The way the graphene sheet is wrapped is represented by a pair of indices  $(n,m)$  called the chiral vector. The integers  $n$  and  $m$  denote the number of unit vectors along two directions in the honeycomb crystal lattice of graphene. If  $m = 0$ , the nanotubes are called "zigzag". If  $n = m$ ,



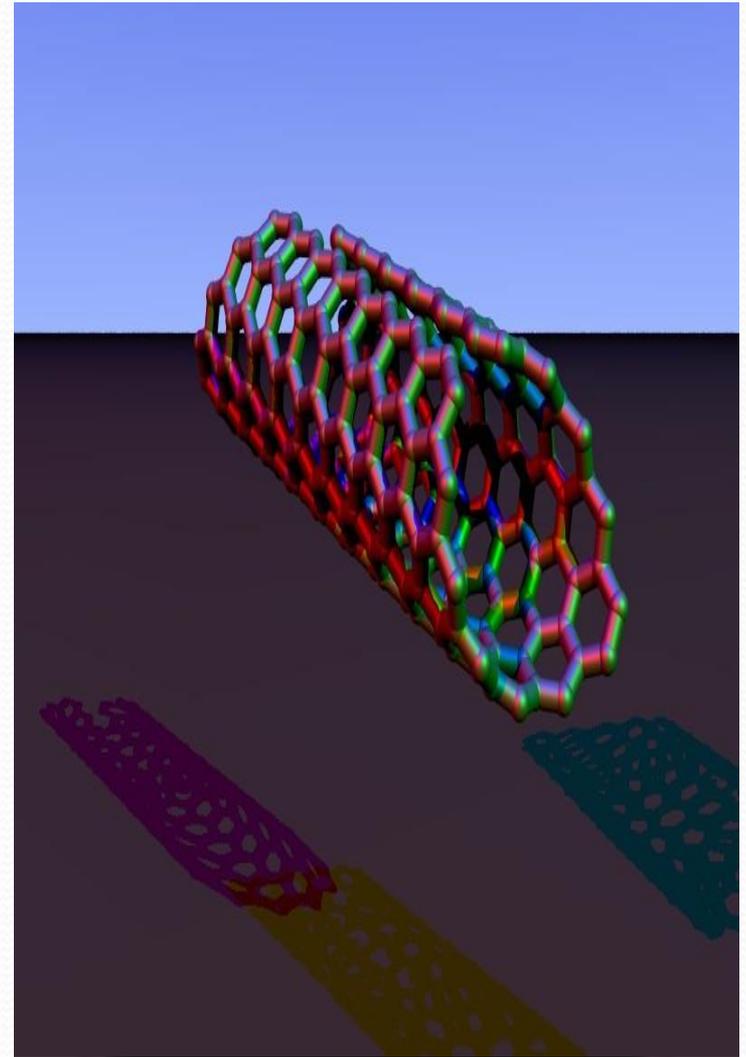
The  $(n,m)$  nanotube naming scheme can be thought of as a vector ( $C_h$ ) in an infinite graphene sheet that describes how to "roll up" the graphene sheet to make the nanotube.  $T$  denotes the tube axis, and  $a_1$  and  $a_2$  are the unit vectors of graphene in real space

- Single-walled nanotubes are an important variety of carbon nanotube because they exhibit electric properties that are not shared by the multi-walled carbon nanotube (MWNT) variants. One useful application of SWNTs is in the development of the first intramolecular field effect transistors (FET). Production of the first intramolecular logic gate using SWNT FETs has recently become possible as well.





Zigzag (n,0)

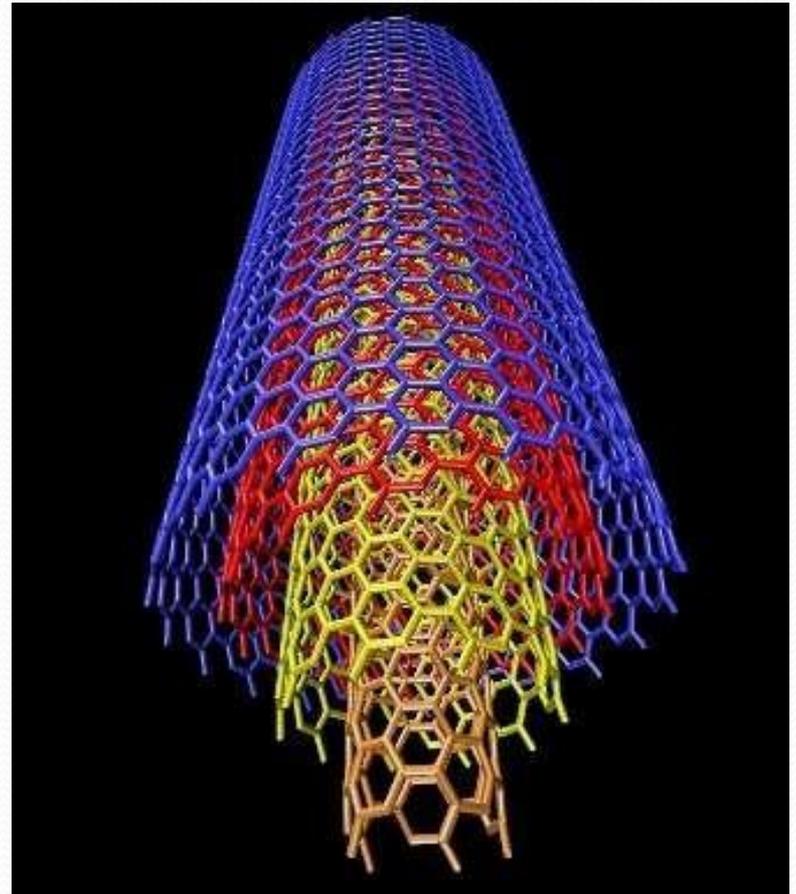


Chiral (n,m)

# Multi-walled

Multi-walled nanotubes (MWNT) consist of multiple rolled layers (concentric tubes) of graphite.

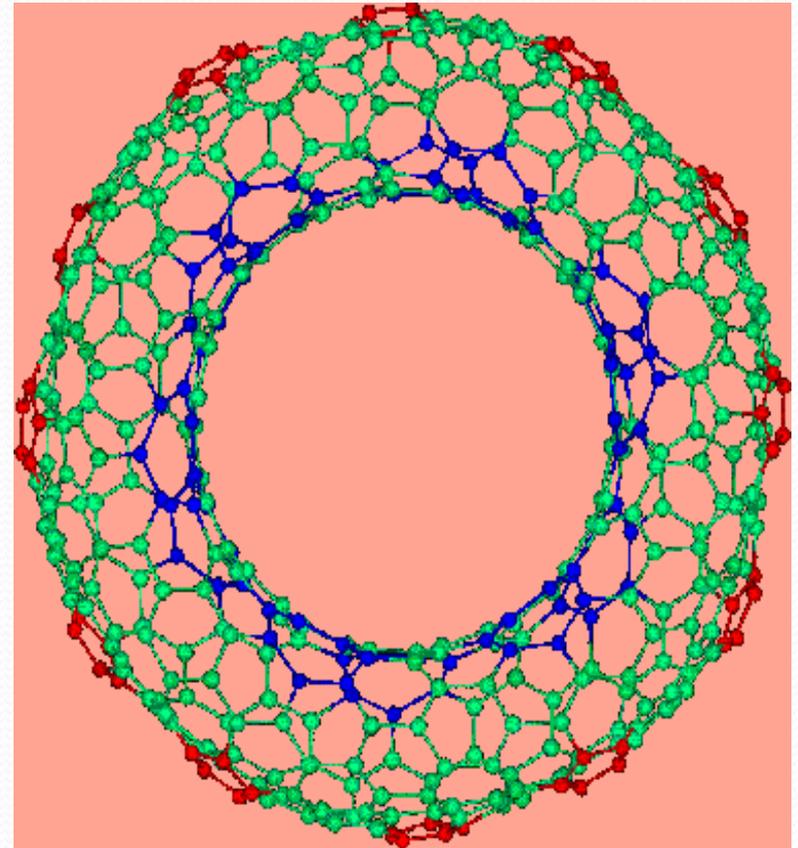
There are two models which can be used to describe the structures of multi-walled nanotubes. In the Russian Doll model, sheets of graphite are arranged in concentric cylinders, e.g. a (0,8) single-walled nanotube (SWNT) within a larger (0,10) single-walled nanotube. In the Parchment model, a single sheet of graphite is rolled in around itself, resembling a scroll of parchment or a rolled newspaper. The interlayer distance in multi-walled nanotubes is close to the distance between graphene layers in graphite, approximately 3.4 Å.



# Toru

## S

- A nanotorus is theoretically described as carbon nanotube bent into a torus (doughnut shape). Nanotori are predicted to have many unique properties, such as magnetic moments 1000 times larger than previously expected for certain specific radii. Properties such as magnetic moment, thermal stability, etc. vary widely depending on radius of the torus and radius of the tube.



# Nanobud

Carbon nanobuds are a newly created material combining two previously discovered allotropes of carbon: carbon nanotubes and fullerenes. In this new material, fullerene-like "buds" are covalently bonded to the outer sidewalls of the underlying carbon nanotube.

This hybrid material has useful properties of both fullerenes and carbon nanotubes. In particular, they have been found to be exceptionally good field emitters.

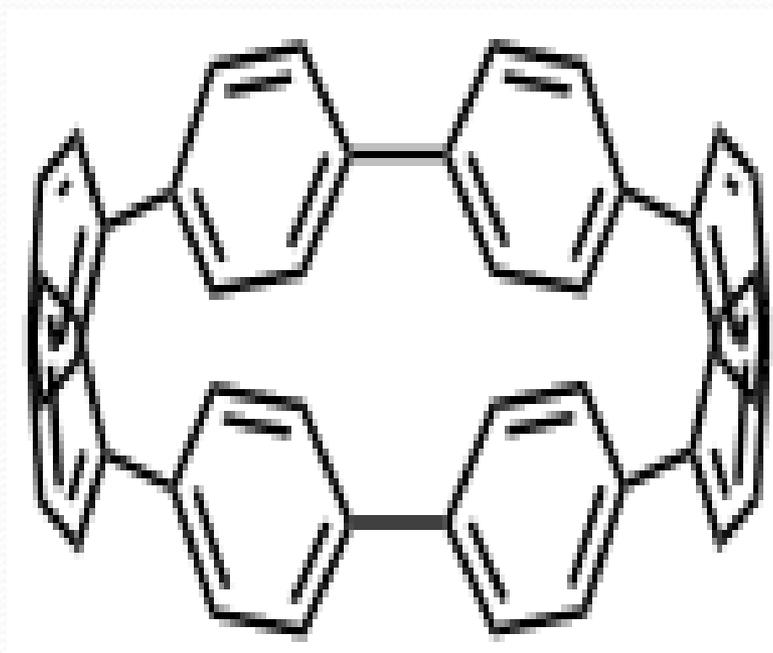
In composite materials, the attached fullerene molecules may function as molecular anchors preventing slipping of the nanotubes, thus improving the



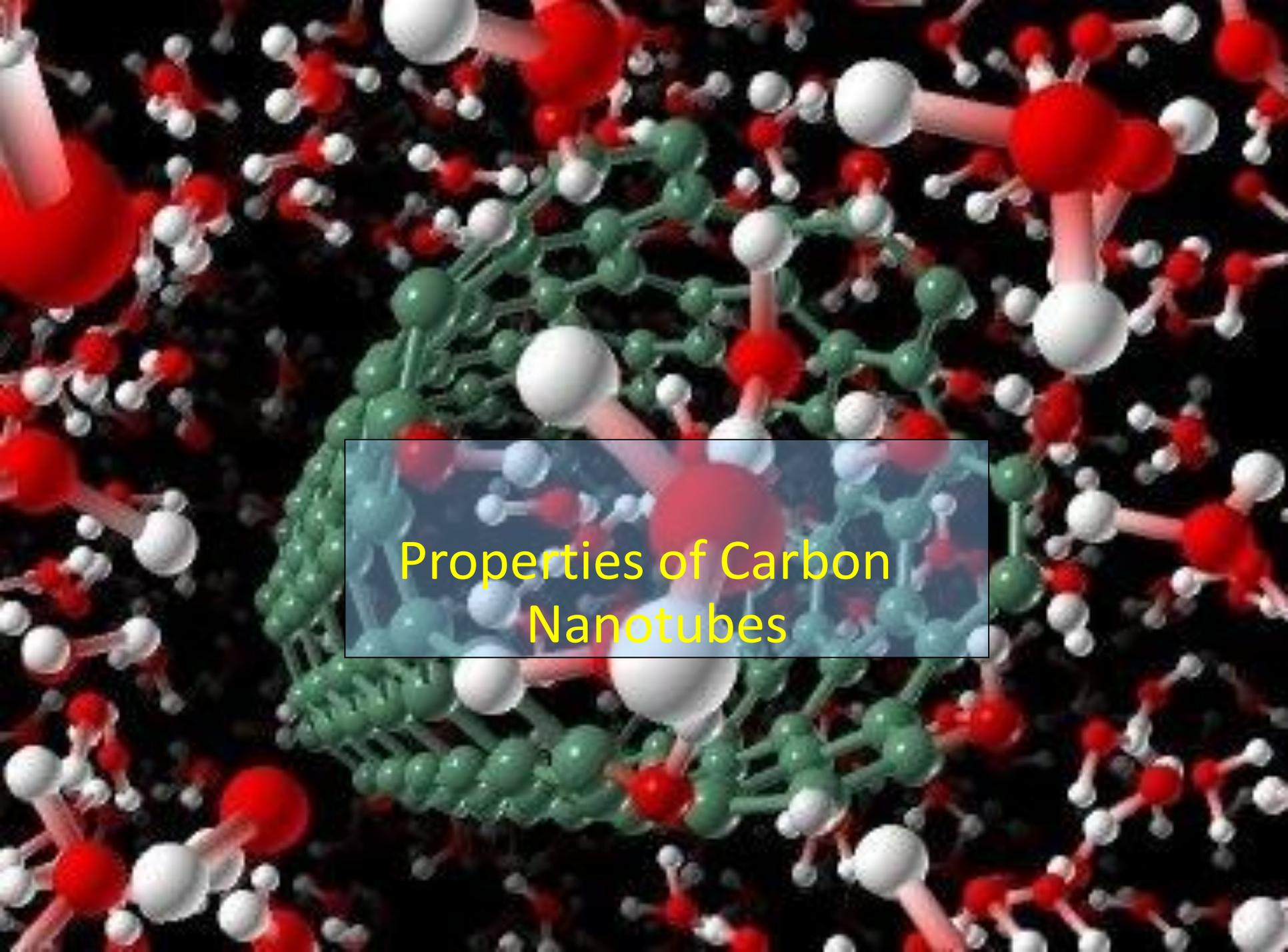
A stable nanobud structure

# Extreme carbon nanotubes

The observation of the longest carbon nanotubes (18.5 cm long) was reported in 2009. They were grown on Si substrates using an improved chemical vapor deposition (CVD) method and represent electrically uniform arrays of single-walled carbon nanotubes. The shortest carbon nanotube is the organic compound cycloparaphenylene which was synthesized in the early 2009. The thinnest carbon nanotube is armchair (2,2) CNT



Cycloparaphenylene



Properties of Carbon  
Nanotubes

# Strength

Carbon nanotubes are the strongest and stiffest materials yet discovered in terms of tensile strength and elastic modulus respectively. This strength results from the covalent  $sp^2$  bonds formed between the individual carbon atoms. In 2000, a multi-walled carbon nanotube was tested to have a tensile strength of 63 gigapascals (GPa). (This, for illustration, translates into the ability to endure tension of a weight equivalent to 6422 kg on a cable with cross-section of  $1 \text{ mm}^2$ .) Since carbon nanotubes have a low density for a solid of  $1.3$  to  $1.4 \text{ g}\cdot\text{cm}^{-3}$ , its specific strength of up to  $48,000 \text{ kN}\cdot\text{m}\cdot\text{kg}^{-1}$  is the best of known materials, compared to high-carbon steel's  $154 \text{ kN}\cdot\text{m}\cdot\text{kg}^{-1}$ . CNTs are not nearly as strong under compression. Because of their hollow structure and high aspect ratio, they tend to undergo buckling when placed under compressive, torsional or bending stress.



# Comparison of mechanical properties

Material	Young's modulus (TPa)	Tensile strength (GPa)	Elongation at break (%)
SWNT	~1 (from 1 to 5)	13–53	16
Armchair SWNT	0.94	126.2	23.1
Zigzag SWNT	0.94	94.5	15.6-17.5
Chiral SWNT	0.92		
MWNT	0.27-0.8--0.95	11-63-150	
Stainless steel	0.186-0.214	0.38-1.55	15-50
Kevlar–29&149	0.06-0.18	3.6-3.8	~2

# Hardness

- Diamond is considered to be the hardest material, and it is well known that graphite transforms into diamond under conditions of high temperature and high pressure. One study succeeded in the synthesis of a super-hard material by compressing SWNTs to above 24 GPa at room temperature. The hardness of this material was measured with a nanoindenter as 62–152 GPa. The hardness of reference diamond and boron nitride samples was 150 and 62 GPa, respectively. The bulk modulus of compressed SWNTs was 462–546 GPa, surpassing the value of 420 GPa for diamond

# Kinetic property

- • Multi-walled nanotubes, multiple concentric nanotubes precisely nested within one another, exhibit a striking telescoping property whereby an inner nanotube core may slide, almost without friction, within its outer nanotube shell thus creating an atomically perfect linear or rotational bearing. This is one of the first true examples of molecular nanotechnology, the precise positioning of atoms to create useful machines. Already this property has been utilized to create the world's smallest rotational motor

# Electrical property

- Because of the symmetry and unique electronic structure of graphene, the structure of a nanotube strongly affects its electrical properties. For a given  $(n,m)$  nanotube, if  $n = m$ , the nanotube is metallic; if  $n - m$  is a multiple of 3, then the nanotube is semiconducting with a very small band gap, otherwise the nanotube is a moderate semiconductor. Thus all armchair ( $n = m$ ) nanotubes are metallic, and nanotubes  $(6,4)$ ,  $(9,1)$  etc. are semiconducting.

# Thermal property

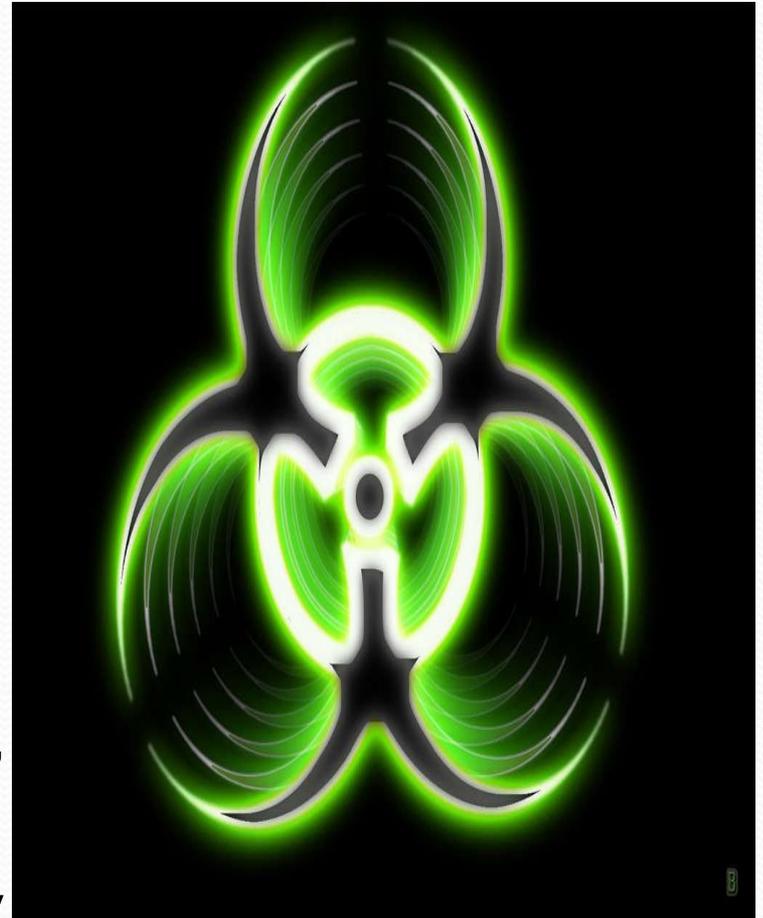
- All nanotubes are expected to be very good thermal conductors along the tube, exhibiting a property known as "ballistic conduction," but good insulators laterally to the tube axis. Measurements show that a SWNT has a room-temperature thermal conductivity along its axis of about  $3500 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ ; compare this to copper, a metal well-known for its good thermal conductivity, which transmits  $385 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ . A SWNT has a room-temperature thermal conductivity across its axis of about  $1.52$

# Defects

- As with any material, the existence of a crystallographic defect affects the material properties. Defects can occur in the form of atomic vacancies. High levels of such defects can lower the tensile strength by up to 85%. Crystallographic defects also affect the tube's electrical properties. A common result is lowered conductivity through the defective region of the tube. Crystallographic defects strongly affect the tube's thermal properties. Such defects lead to phonon scattering, which in turn increases the relaxation rate of the phonons. This reduces the mean free path and reduces the thermal conductivity of nanotube structures.

# Toxicity

Determining the toxicity of carbon nanotubes has been one of the most pressing questions in nanotechnology. Unfortunately such research has only just begun and the data are still fragmentary and subject to criticism. Preliminary results highlight the difficulties in evaluating the toxicity of this heterogeneous material. Parameters such as structure, size distribution, surface area, surface chemistry, surface charge, and agglomeration state as well as purity of the samples, have considerable impact on the reactivity of carbon nanotubes. However, available data clearly show that, under some conditions, nanotubes can cross membrane barriers, which suggests that if raw materials reach the organs they can induce harmful effects such as inflammatory and fibrotic reactions.



# Synthesis

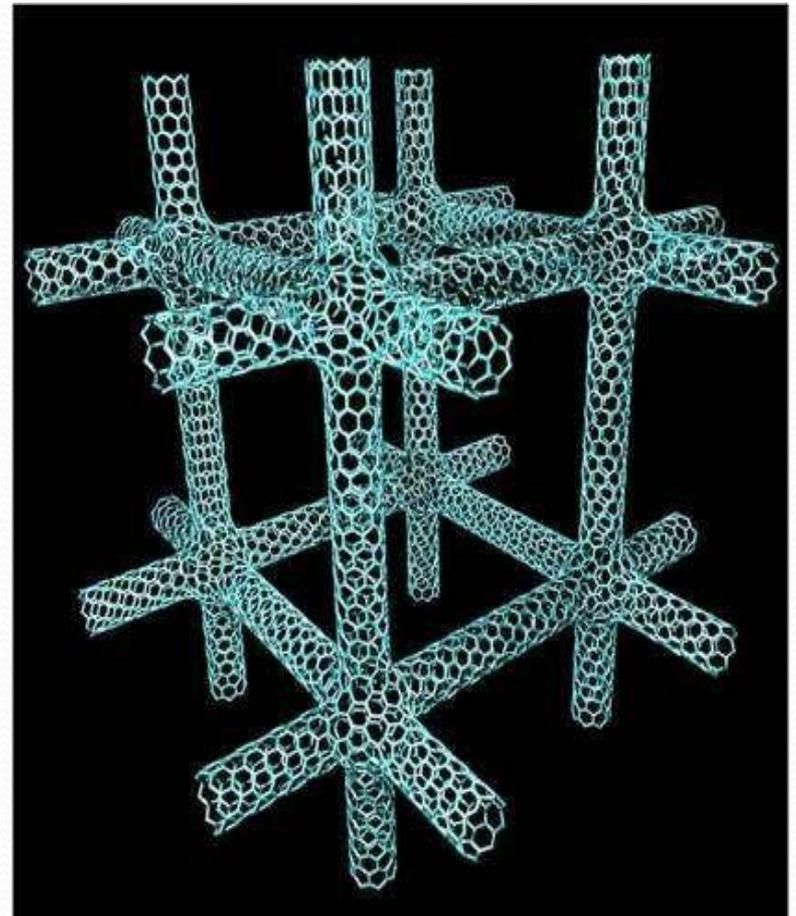
- ✓ Techniques have been developed to produce nanotubes in sizeable quantities, some of them are:-

Arc discharge Laser

ablation

- ✓ Chemical vapor deposition
- ✓ (CVD)

- ✓



# Arc discharge

Nanotubes were observed in 1991 in the carbon soot of graphite electrodes during an arc discharge, by using a current of 100 amps, that was intended to produce fullerenes. However the first macroscopic production of carbon nanotubes was made in 1992 by two researchers at NEC's Fundamental Research Laboratory. During this process, the carbon contained in the negative electrode sublimates because of the high discharge temperatures.

Because nanotubes were initially discovered using this technique, it has been the most widely-used method of nanotube synthesis. The yield for this method is up to 30 percent by weight and it produces both single- and multi-walled nanotubes with lengths of up to

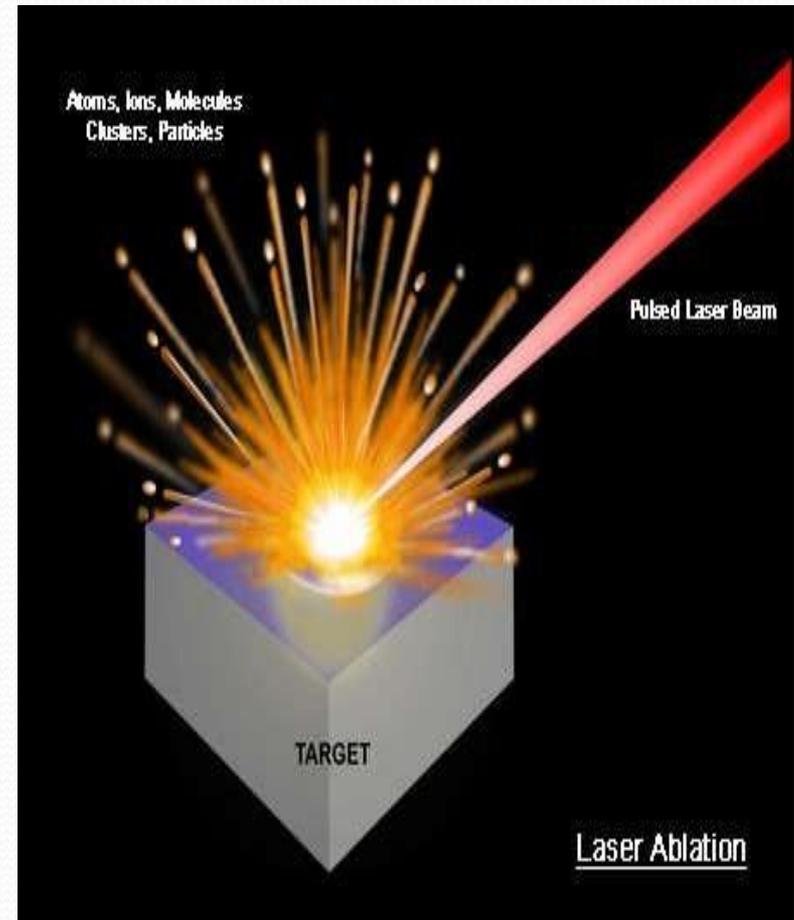
50 micrometers with few structural defects.



Powder of carbon nanotubes

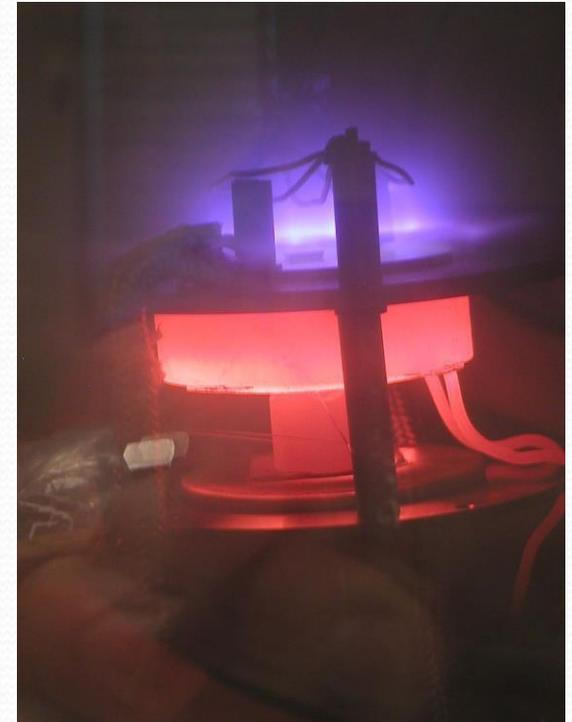
# Laser ablation

- In the laser ablation process, a pulsed laser vaporizes a graphite target in a high-temperature reactor while an inert gas is bled into the chamber. Nanotubes develop on the cooler surfaces of the reactor as the vaporized carbon condenses. A water-cooled surface may be included in the system to collect the nanotubes. The laser ablation method yields around 70% and produces primarily single-walled carbon nanotubes with a controllable diameter determined by the reaction temperature. However, it is more expensive than either arc discharge or chemical vapor deposition.



# Chemical vapor deposition (CVD)

- During CVD, a substrate is prepared with a layer of metal catalyst particles, most commonly nickel, cobalt, iron, or a combination. The metal nanoparticles can also be produced by other ways, including reduction of oxides or oxides solid solutions. The diameters of the nanotubes that are to be grown are related to the size of the metal particles. This can be controlled by patterned (or masked) deposition of the metal, annealing, or by plasma etching of a metal layer. The substrate is heated to approximately 700°C. To initiate the growth of nanotubes, two gases are bled into the reactor: a process gas (such as ammonia, nitrogen or hydrogen) and a carbon-containing gas (such as acetylene, ethylene, ethanol or methane). Nanotubes grow at the sites of the metal catalyst; the carbon-containing gas is broken apart at the surface of the catalyst particle, and the carbon is transported to the edges of the particle, where it forms the nanotubes.

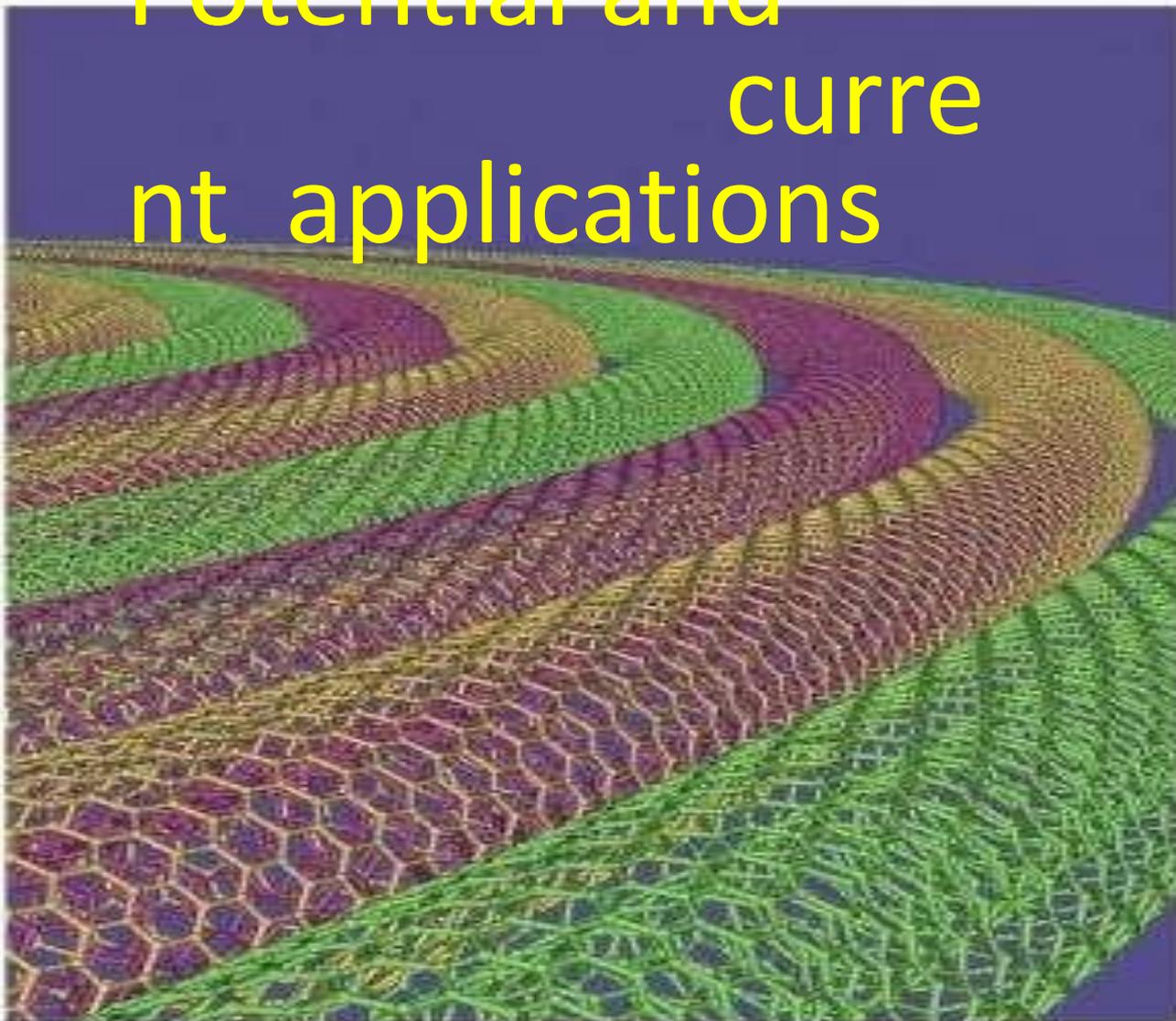


Nanotubes being grown by plasma enhanced chemical vapor deposition

# Natural, incidental, and controlled flame environments

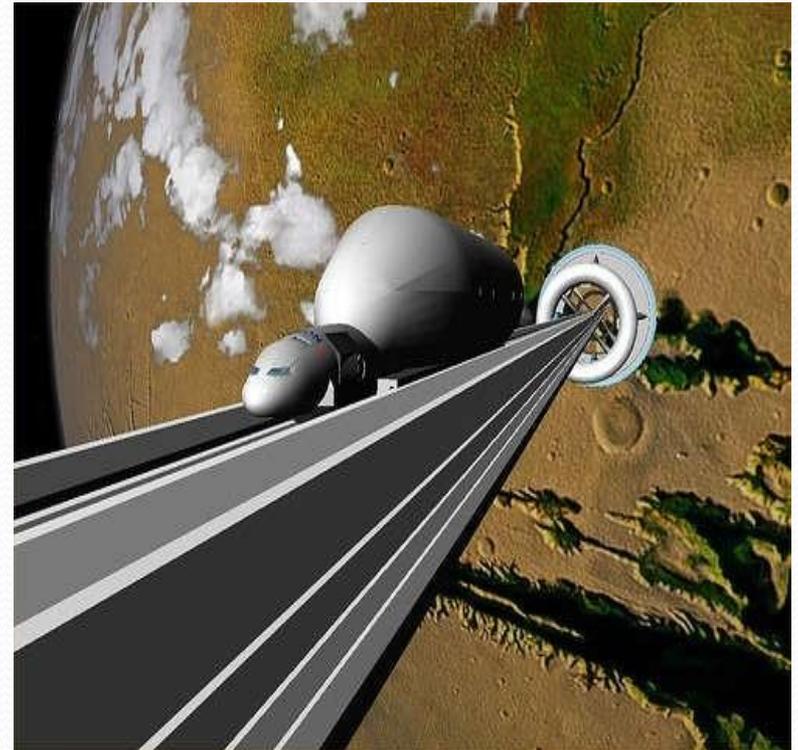
- Fullerenes and carbon nanotubes are not necessarily products of high-tech laboratories; they are commonly formed in such mundane places as ordinary flames, produced by burning methane, ethylene, and benzene, and they have been found in soot from both indoor and outdoor air. However, these naturally occurring varieties can be highly irregular in size and quality because the environment in which they are produced is often highly uncontrolled. Thus, although they can be used in some applications, they can lack in the high degree of uniformity necessary to satisfy the many needs of both research and industry.

# Potential and current applications



# Structural Applications

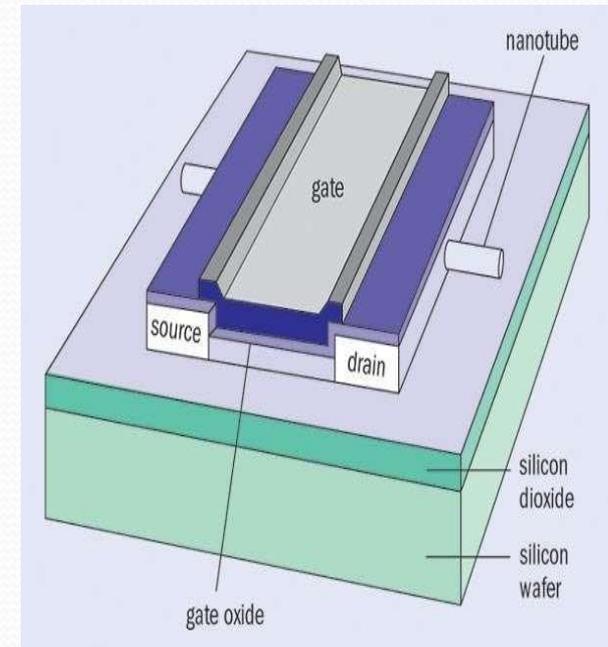
- Because of the carbon nanotube's superior mechanical properties, many structures have been proposed ranging from everyday items like clothes and sports gear to combat jackets and space elevators. However, the space elevator will require further efforts in refining carbon nanotube technology, as the practical tensile strength



A Space Elevator

# In electrical circuits

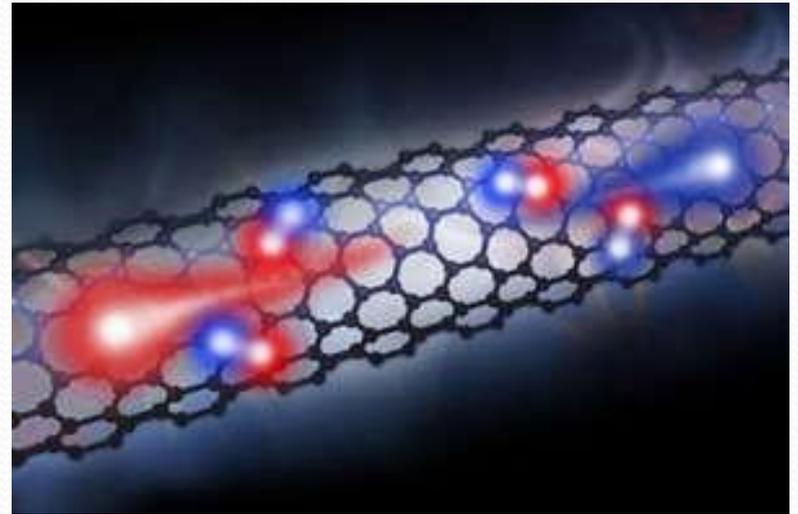
- Nanotube based transistors have been made that operate at room temperature and that are capable of digital switching using a single electron. The first nanotube integrated memory circuit was made in 2004. One of the main challenges has been regulating the conductivity of nanotubes. Depending on subtle surface features a nanotube may act as a plain conductor or as a semiconductor. A fully automated method has however been developed to remove non-semiconductor tubes. Large structures of carbon nanotubes can be used for thermal management of electronic circuits. An approximately 1 mm-thick carbon nanotube layer was used as a special material to fabricate coolers, this material has very low density, ~20 times lower weight than a similar copper structure, while the cooling properties are similar for the two materials. Overall, incorporating carbon nanotubes as transistors into logic-gate circuits with densities comparable to modern CMOS technology has not yet been demonstrated.



Nanotube Transistor

# Solar cells

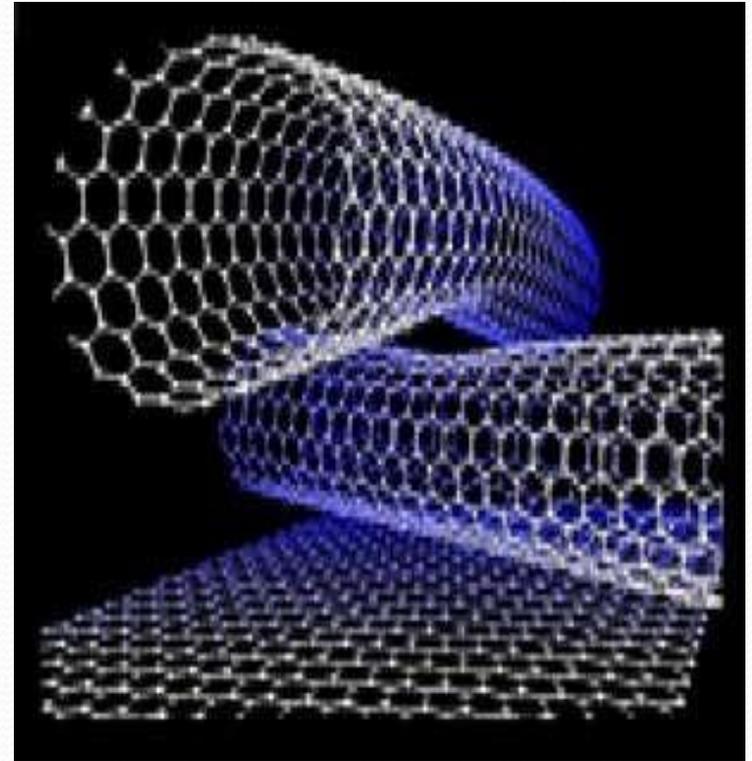
- Solar cells developed at the New Jersey Institute of Technology use a carbon nanotube complex, formed by a mixture of carbon nanotubes and carbon buckyballs (known as fullerenes) to form snake-like structures. Buckyballs trap electrons, although they can't make electrons flow. Add sunlight to excite the polymers, and the buckyballs will grab the electrons. Nanotubes,



Nanotube based solar cell

# As paper batteries

- A paper battery is a battery engineered to use a paper-thin sheet of cellulose (which is the major constituent of regular paper, among other things) infused with aligned carbon nanotubes. Scientists at Stanford University have developed lightweight, pliable batteries that are so light they are compared to feathers. These ultra-light batteries have been described as supercapacitors and resemble paper. By utilizing carbon nanotubes and silver nanowires, scientists at Stanford have been able to coat a

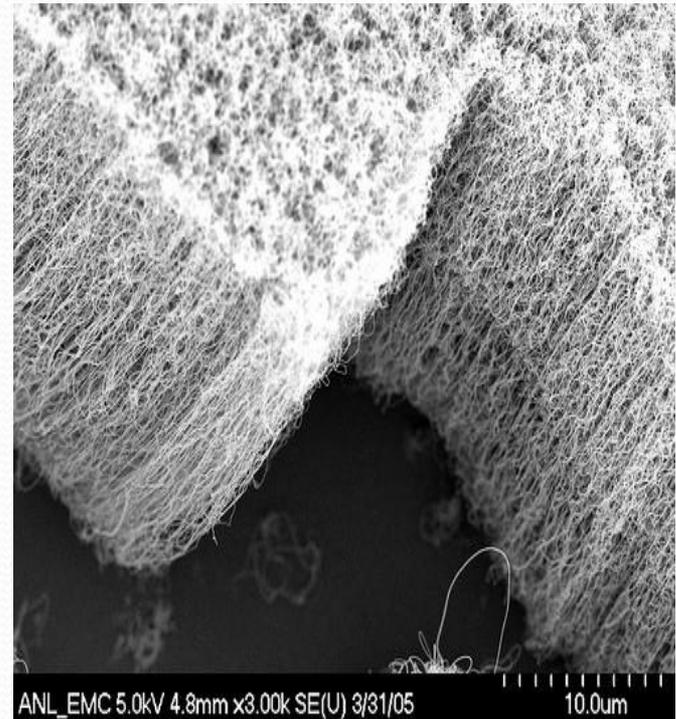


Paper Battery

# Other applications

- Carbon nanotubes have been implemented in nanoelectromechanical systems, including mechanical memory elements (NRAM being developed by Nantero Inc.) and nanoscale electric motors. A nanoradio, a radio receiver consisting of a single nanotube, was demonstrated in 2007. In 2008 it was shown that a sheet of nanotubes can operate as a loudspeaker if an alternating current is applied. The sound is not produced through vibration but thermoacoustically.

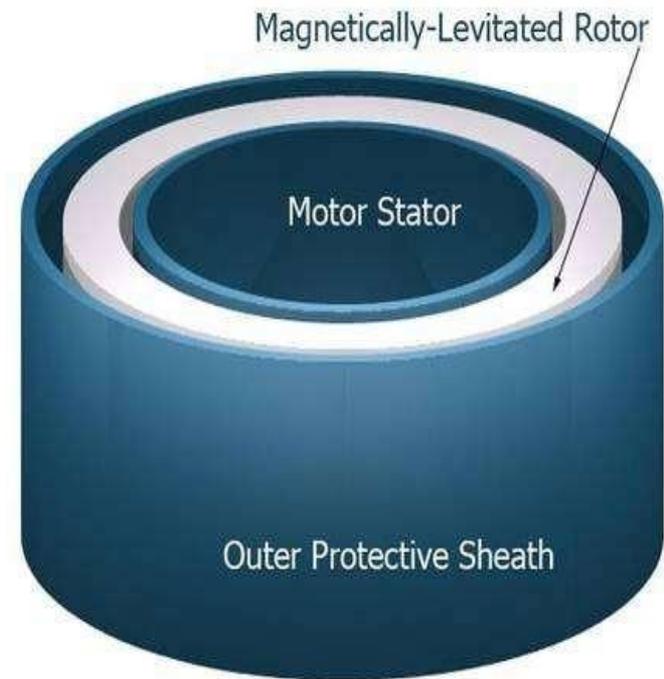
Because of the high mechanical strength of carbon nanotubes, research is being made into weaving them into clothes to create stab-proof and bulletproof clothing. The nanotubes would effectively stop the bullet



Aligned nanotubes are preferred for many applications

# Other applications

- A flywheel made of carbon nanotubes could be spun at extremely high velocity on a floating magnetic axis in a vacuum, and potentially store energy at a density approaching that of conventional fossil fuels. Since energy can be added to and removed from flywheels very efficiently in the form of electricity, this might offer a way of storing electricity, making the electrical grid more efficient and variable power suppliers (like wind turbines) more useful in meeting energy needs. The practicality of this depends heavily upon the cost of making



A Flywheel



*Thank you!*