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What is Nanotechnology?

SHINE: Seattle's Hub for Industry-driven Nanotechnology Education

North Seattle College

What is Nanotechnology?

Nanotechnology is….

- the control of matter on the atomic level
- the ability to build using atoms as building blocks
- the manufacture of novel materials with novel properties

What is a nanometer?

- 1 nm = 10^{-9} m = 0.000000001 m = one billionth of a meter

What is a nanostructure?

- Structure with at least one dimension < 100 nm

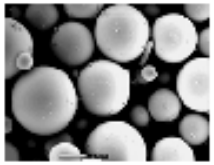
The Scale of Things – Nanometers and More

Things Natural

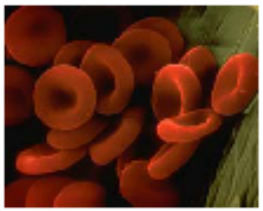
Dust mite
200 µm

Ant
~ 5 mm

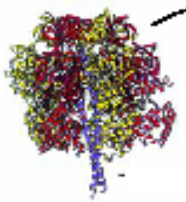
Human hair
~ 60-120 µm wide



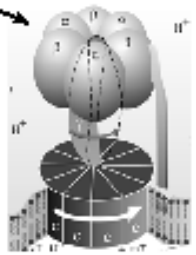
Fly ash
~ 10-20 µm



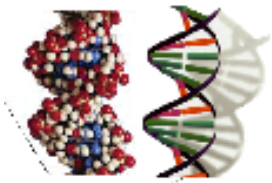
Red blood cells
(~7-8 µm)



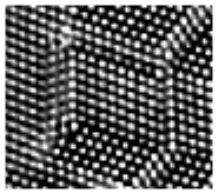
~10 nm diameter



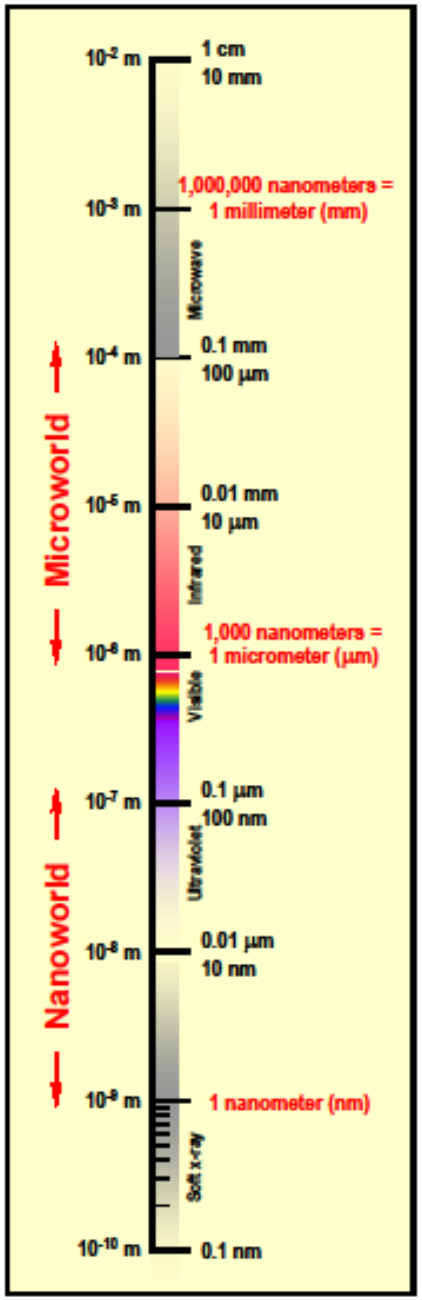
ATP synthase



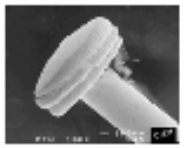
DNA
~2-1/2 nm diameter



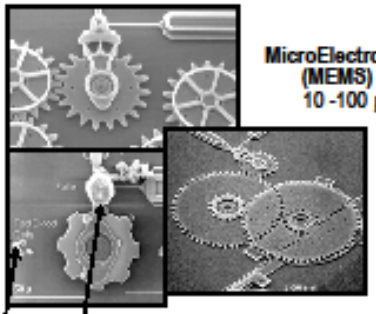
Atoms of silicon
spacing ~tenths of nm



Things Manmade

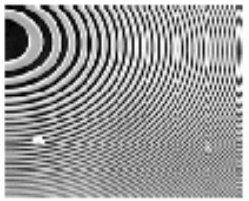


Head of a pin
1-2 mm

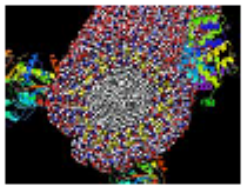


MicroElectroMechanical (MEMS) devices
10 -100 µm wide

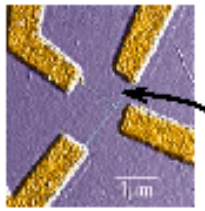
Pollen grain
Red blood cells



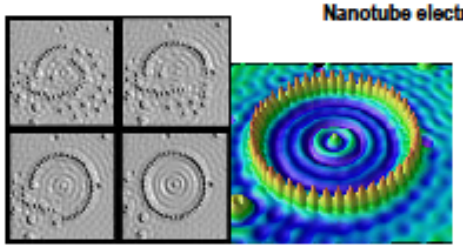
Zone plate x-ray "lens"
Outer ring spacing ~35 nm



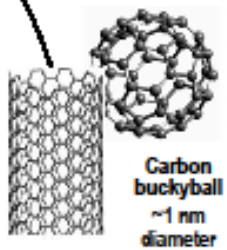
Self-assembled,
Nature-inspired structure
Many 10s of nm



Nanotube electrode



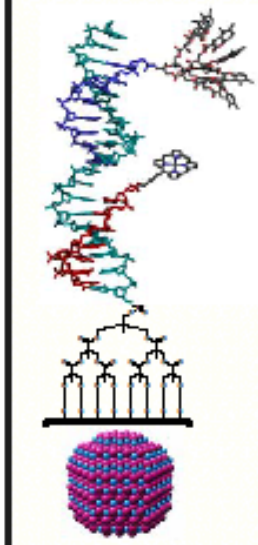
Quantum corral of 48 iron atoms on copper surface
positioned one at a time with an STM tip
Corral diameter 14 nm



Carbon buckyball
~1 nm diameter

Carbon nanotube
~1.3 nm diameter

The Challenge



Fabricate and combine nanoscale building blocks to make useful devices, e.g., a photosynthetic reaction center with integral semiconductor storage.

Office of Basic Energy Sciences
Office of Science, U.S. DOE

Why Study Nanoscience and Nanotechnology?

Nanoscience:

The study of fundamental principles of nanostructures between bulk and atomic properties.

Nanotechnology:

The application of nano-structures into useful devices.

The Very Beginnings…

500 – 1400 – Stained Glass

800 - 1600 – Nanoparticles in pottery

1200 - 1700 – Damascus Steel swords

~1910 – Particle sizes described in "nanometers"

1959 – Feynman's speech:

"The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom"

Then…

1970 – “Nanotechnology” coined (Taniguchi)

1981 – First atoms seen (Binnig and Rohrer, STM)

1986 – Engines of Creation, the Coming Age of Nanotechnology by Richard Drexler

“Nanotechnology is the principle of atom manipulation atom by atom, through control of the structure of matter at the molecular level. It entails the ability to build molecular systems with atom-by-atom precision, yielding a variety of nanomachines”

Now...

Why “Nano” is Interesting

Particles are small

- High surface-to-volume ratio
- React differently
- Act differently (new properties)
- Interact with light differently
- Are on the scale of small biological structures

Quantum Mechanics meet Classical Mechanics

Interesting “new” structures

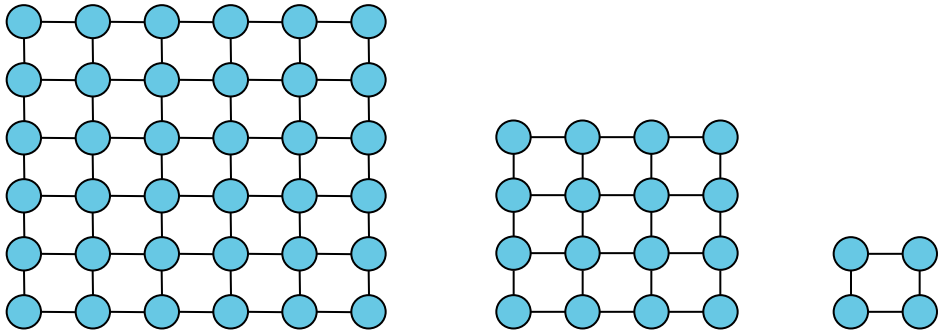
Interesting materials with nanoparticles embedded

Surface Area and Energy

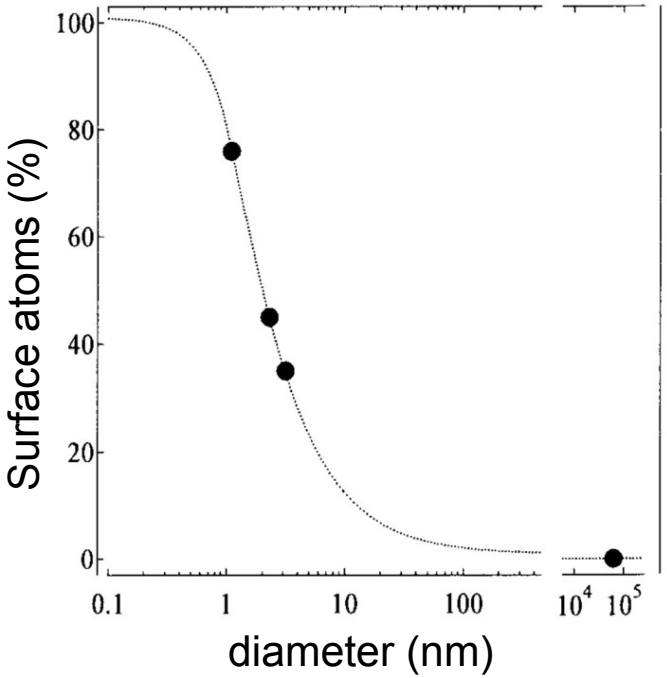
Surface energy increases with surface area

Large surface energy = instability

Driven to grow to reduce surface energy



Surface area vs particle size



C. Nutzenadel et al., *Eur. Phys. J. D.* **8,** 245 (2000).

Physical Structure → Physical Property

What are the structural differences on the nanoscale?

- High percentage surface atoms
- Spatial confinement
- Reduced imperfections

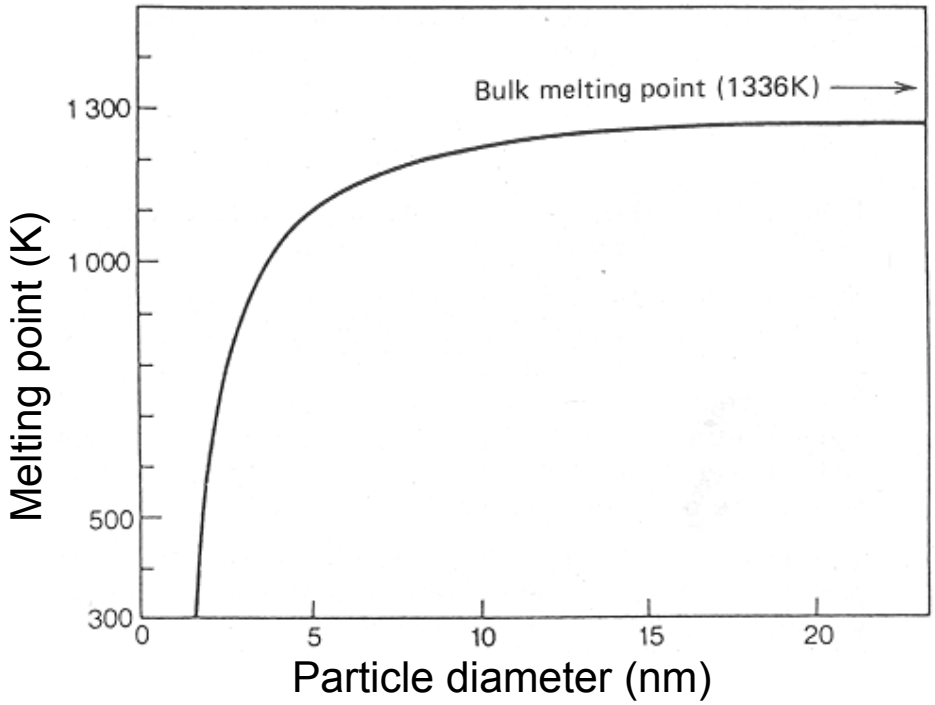
What properties are affected?

What properties can we tune?

Melting Points

Lower melting point for nanostructures <100 nm

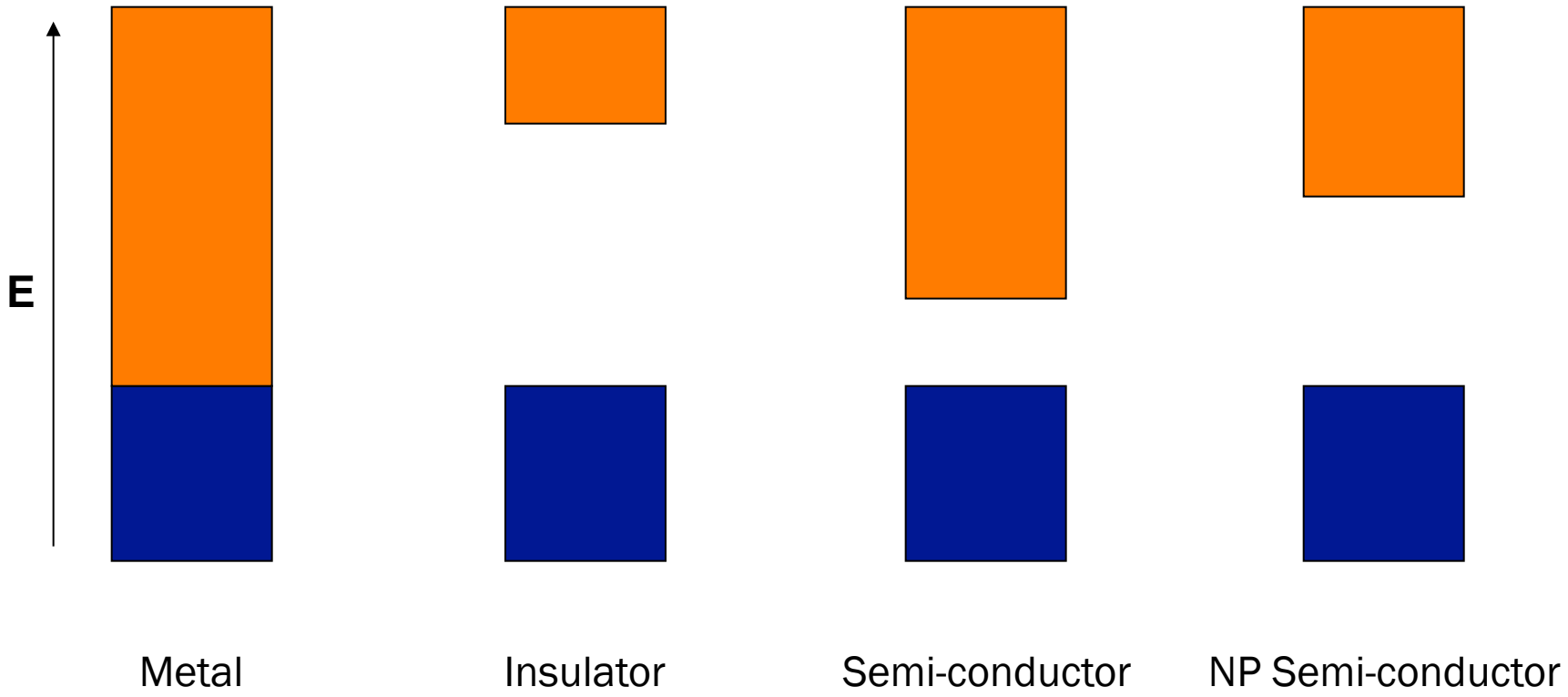
Surface energy increases as size decreases



Ichimose, N. et al. *Superfine Particle Technology* Springer-Verlag London, 1992.

Electrical Properties

Band gap increases as particle size decreases

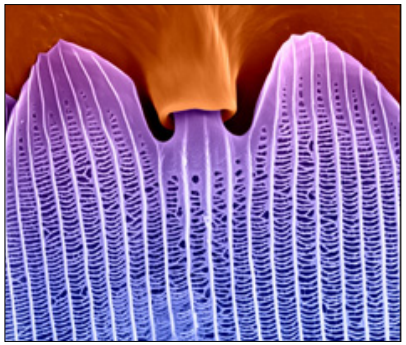


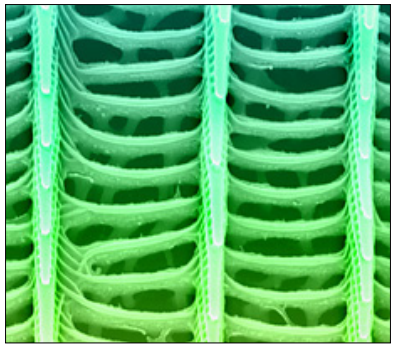
Particles & Light

Particles interact differently with light


1X


220X


5000X


20,000X

Militaries Study Animals for Cutting-Edge Camouflage. James Owen in England for National Geographic News March 12, 2003, Proc. R. Soc. Lond. B (1999) 266, 1403-1411

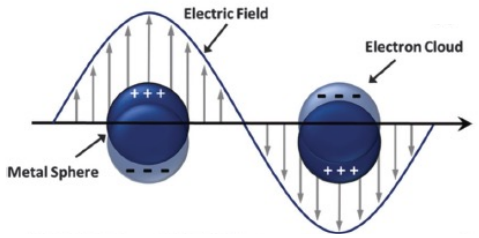
Structures are smaller than wavelength of visible light

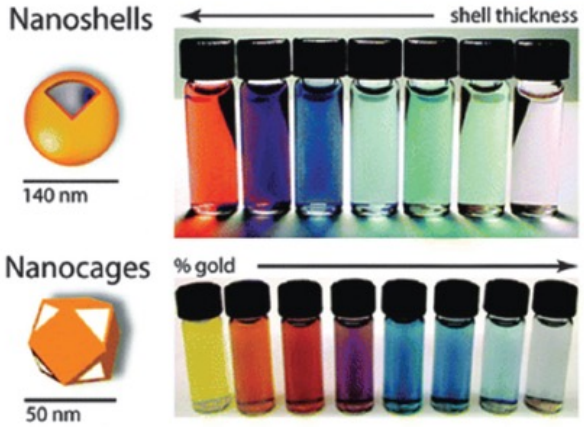
- Photonic Crystals
- Surface Plasmon Resonance
- Quantum Dot Fluorescence

Optical Properties

Surface Plasmon Resonance

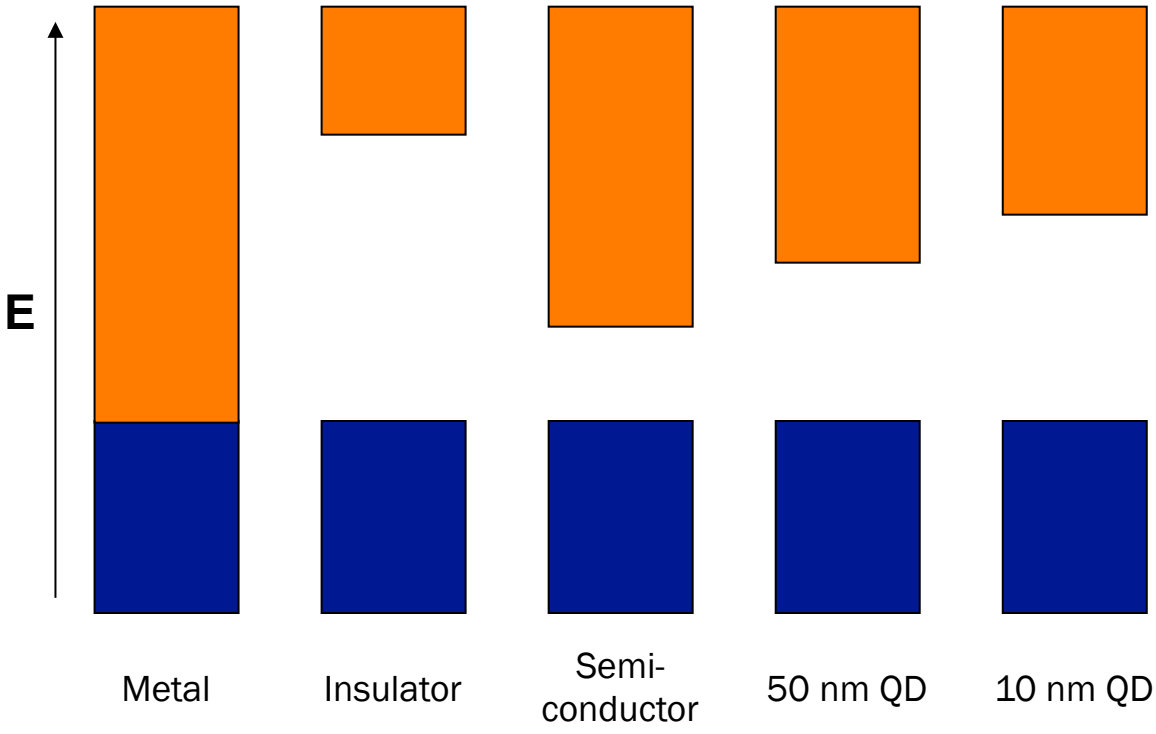
- Interaction of light with metallic nanoparticle surfaces
- Coupling of free electrons and incident light
- Localized coherent oscillation of electrons
- Tunable optical properties of nanostructures; depends on size, shape, composition, and environment

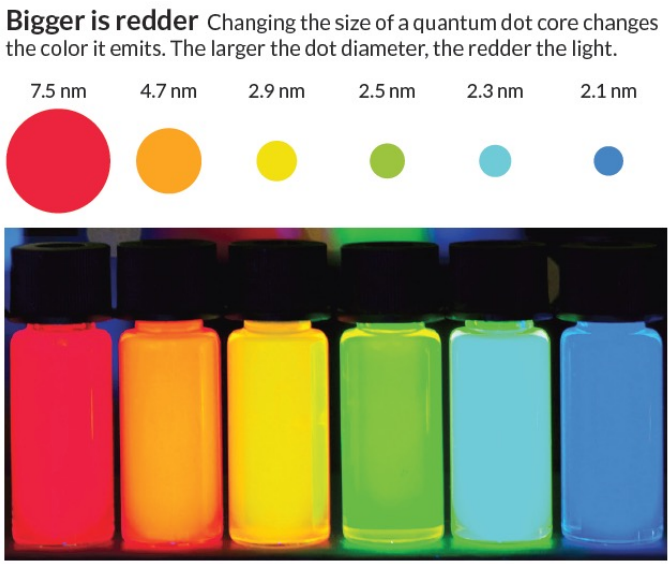




Optical Properties: Quantum Dots

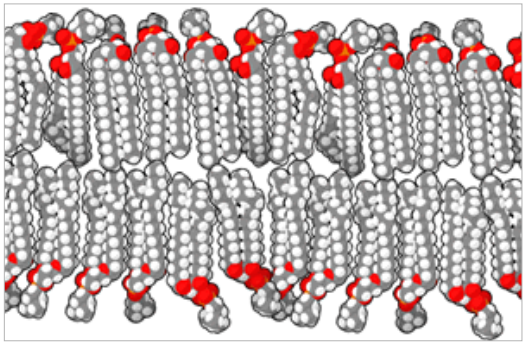
Band gap increases as particle size decreases



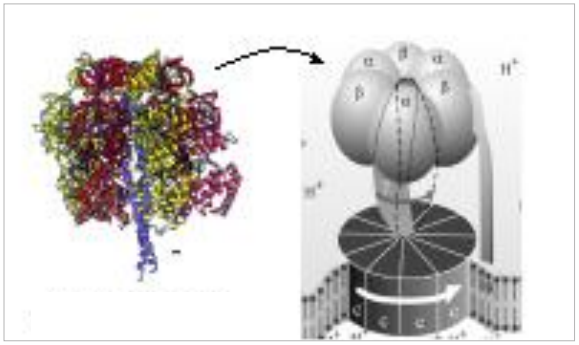


Size: Biological Structures

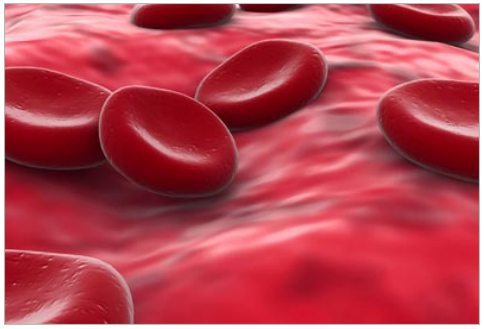
2 nm diameter



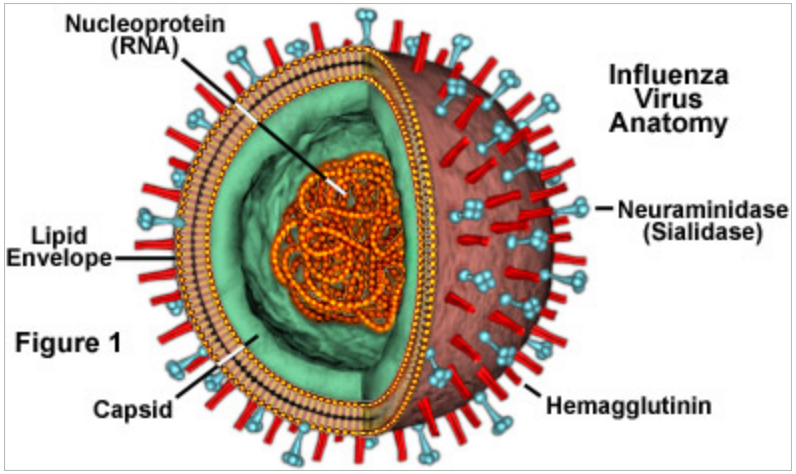
~5 nm thick



~10 nm diameter

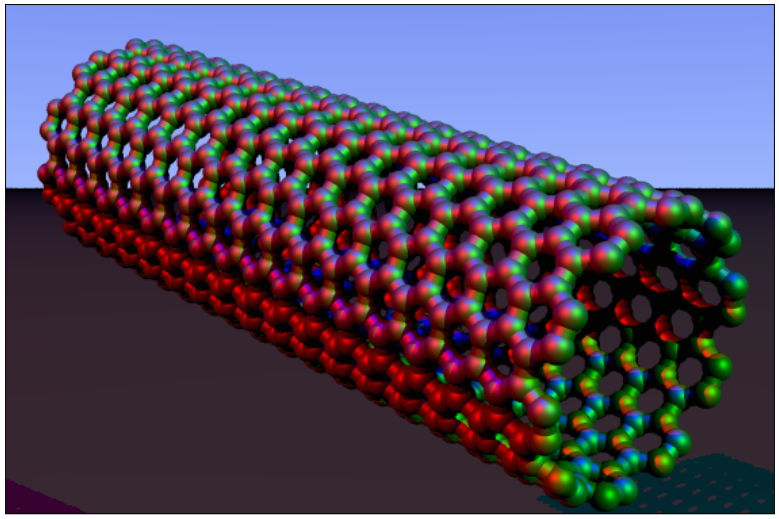


5000 nm diameter



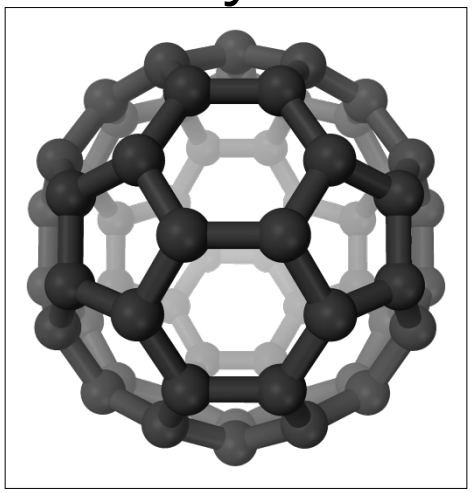
~50 – 100 nm diameter

Unique Structures



Carbon Nanotubes

Buckyballs



Zeolites

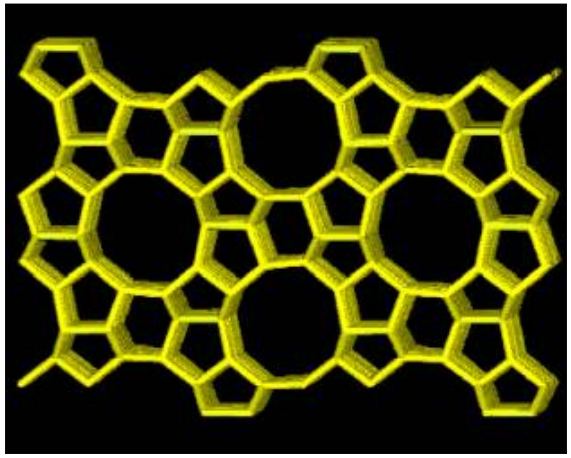


Image References

Slide 3	*The Scale of Things.* [Online file]. 09 Nov 2015. <http://www.nist.gov/pml/wmd/metric/upload/doe-scale-of-things-18-jan-05.pdf>.
Slide 5	*The South rose window of Notre Dame Cathedral, ca 1250. Polychrome lustreware bowl, 9th C, Iraq, British Museum. Damascus saber.* [Online images]. 02 Nov. 2015. <http://www.nano.gov/timeline>
Slide 7	*Process Engineer at Nano3 Facility.* [Online image]. 02 Nov. 2015. <http://ucsdnews.ucsd.edu/pressrelease/nsf_locates_national_nanotechnology_coordinated_infrastructure_site_at_uc_s> *Female Scientist Pipetting*. [Online image]. 02 Nov. 2015. <http://www.nnin.org/news-events/spotlights/nanotechnology-careers>
Slide 9	C. Nutzenadel et al., *Eur. Phys. J. D.* 8, 245 (2000).
Slide 11	Ichimose, N. et al. Superfine Particle Technology Springer-Verlag London, 1992.

Image References

Slide 13	*Militaries Study Animals for Cutting-Edge Camouflage. James Owen in England for National Geographic News. March 12, Proc. R. Soc. Lond. B (1999) 266, 1403-1411* (Penn State NACK Educational Resources, 2009).
Slide 14	Motl, N.E. et al., *Chem. Soc. Rev*., 43, 3823 (2014).
Slide 15	Witze, A., DAZZLING Dots. (Cover Story). *Science News* 188.1 (2015): 22-25. *Academic Search Premier*. Web. 9 Nov. 2015.
Slide 16	*Red blood cells.* [Online image]. 09 Aug. 2010. <http://www.topnews.in/health/files/Red-Blood-Cells.jpg>. *DNA double helix*. [Online image]. 09 Aug. 2010 <http://www.biojobblog.com/uploads/image/dna_500.jpg>. *Lipid bilayer.* [Online image]. 09 Aug. 2010 <http://upload.wikimedia.org/wikipedia/commons/f/f0/Lipid_bilayer_section.gif>.

Image References

Slide 16	*ATP synthase*. [Online image]. 09 Aug. 2010. *Adapted.* <http://www.er.doe.gov/bes/scale_of_things.html>. *Flu virus*. [Online image]. 09 Aug. 2010. <http://www.chm.bris.ac.uk/webprojects2006/Kelly/influenzafigure1.jpg>
Slide 17	*Carbon nanotube: <http://en.wikipedia.org/wiki/File:Carbon_nanotube_armchair_povray.PNG>* *Buckyball: <https://en.wikipedia.org/wiki/Buckminsterfullerene#/media/File:Buckminsterfullerene-perspective-3D-balls.png>* *Zeolite: <http://chemeducator.org/sbibs/s0004003/spapers/430114wv.htm>*

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