What will I get from this class?

Nanotechnology: The Basics

Week 1, Lecture 1

- Why Nanotechnology? Latest human toolmaking
- Class philosophy and target audiences
- Course structure, rhythm and expectations

What Makes Us Human?

When Humans Learn to Make New Materials→ CHANGE

Hunter-Gatherer

The **STONE** Age

Agrarian

Wikimedia, Calame

The BRONZE Age

Cities

Commons 3.0

The **IRON** Age

Materials and Tools: They STILL Matter!

Extremely pure ingot of silicon -- Czochralski process

What comes next for humans and our tools?

STONE AGE – humans learned to fashion tools from rock

BRONZE AGE – humans learned to smelt copper

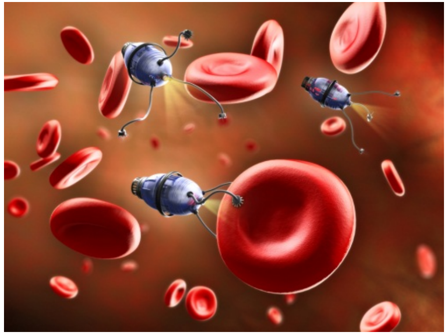
IRON AGE – humans learned to forge iron and steel

INFORMATION age – humans learned to purify silicon

____________________ age – humans learned to make nanoscale materials

Nanotechnology's Future: Around the corner or close?

Wearable computers



Smart Medicines

Space Elevators

Course Objectives

1. To define nanotechnology
2. To explain the importance of material size
3. To distinguish current vs. future nanotechnology
4. To illustrate ‘dry’ nanotechnology in electronics, magnetics and photonics

Who are you?

- A technical student who is exploring nanotechnology as a possible career or focus for advanced degrees
- An adult learner with a keen interest in new technology and futuristic ideas
- Not an expert in nanotechnology, chemistry or physics (!)
- A BUSY person

Breaking Down Nanotechnology

Week 1: Introduction	Week 2: Nanoelectronics	Week 3: Nanomagnetics	Week 4: Nanophotonics
Watch lecture videos Do weekly quiz	Watch lecture videos Do weekly quiz	Watch lecture videos Do weekly quiz	Watch lecture videos Take the last quiz, final

Certificate with distinction

Our Philosophy: Edit, engage and explain

EDIT lecture content to avoid overload
ENGAGE students through forums, demos, talk shows, provocative surveys
EXPLAIN key ideas in multiple ways so as to make a real and lasting impression

Your Three Take-Homes

Week 1, Lecture 1, Nanotechnology

- Why Nanotechnology? Latest human toolmaking
- This class: a 12 hour science show you participate in!
- You = motivated (2-3 hours/week) and knowledgeable

Defining Nanotechnology

Nanotechnology: The Basics

Week 1, Lecture 2

- Nanotechnology: diverse perspectives
- Formal definition: small (1 – 100 nm) and strange
- Nanomaterials=NanoX

Talking About Nanotechnology

" Nanotechnology now represents no less than the next industrial revolution"

" Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications"

"Anything is nanotechnology that, under the rubric of nanotechnology, makes money."

"Nanotechnology is nothing more than new age colloid science."

Anonymous senior engineering professor, 2001 (to your professor)

Red Herring Dec 2001 A technology magazine

Scientific American, 2006, a popular science magazine

Anonymous entrepreneur, Rice Alliance event, 2006

Which quote is YOUR personal favorite? Take the PROVOCATIVE survey

Defining Nanotechnology

From E56 ASTM terminology standard – free on www.astm.org

nanotechnology, *n*—A term referring to a wide range of technologies that measure, manipulate, or incorporate materials and/or features with at least one dimension bet… …eters (nm). Such applications exp… …olecular systems, of nanoscale comp…

Mate…

Critic…

Really bizarre and unusual properties

Nanotechnology contains stuff that is really SMALL and STRANGE

US Government Defines Nanotechnology

Nanotechnology is science, engineering, and technology conducted at the nanoscale, which is about 1 to 100 nanometers.

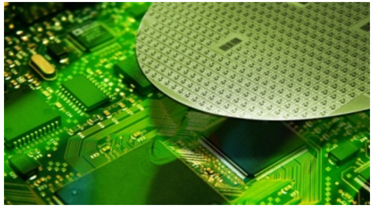
Nanoscience and nanotechnology are the study and application of extremely small things and can be used across all the other science fields, such as chemistry, biology, physics, materials science, and engineering.

Go read http://www.nano.gov/nanotech-101/what/definition

Nanomaterial versus Nanotechnology

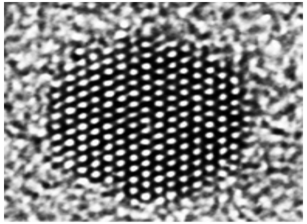
MATERIAL

DEVICE

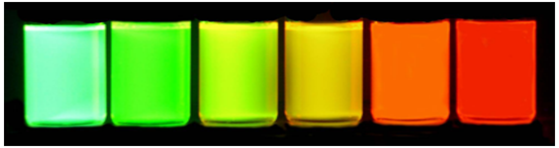


TECHNOLOGY

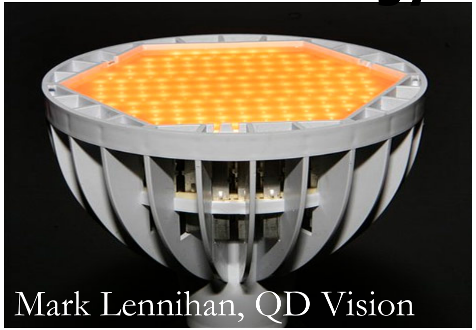
NANOMATERIAL



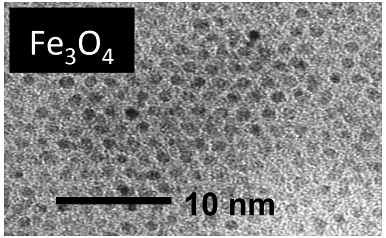
Nanoscale device or property

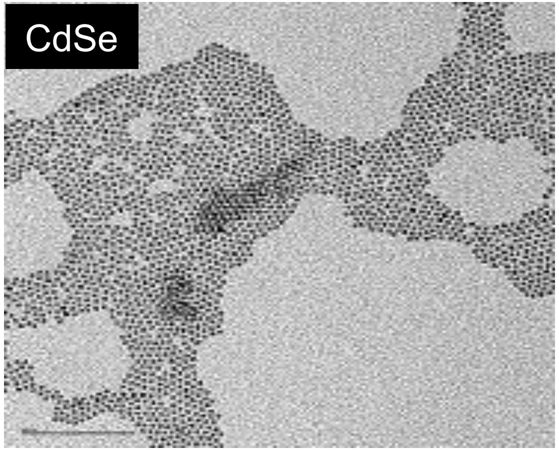


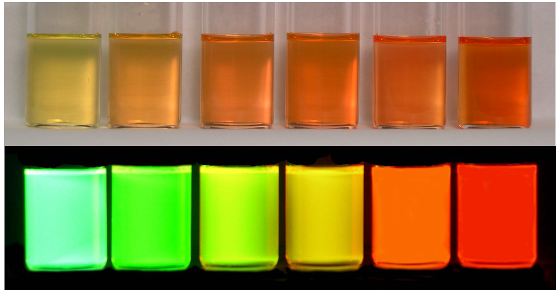
Nanotechnology

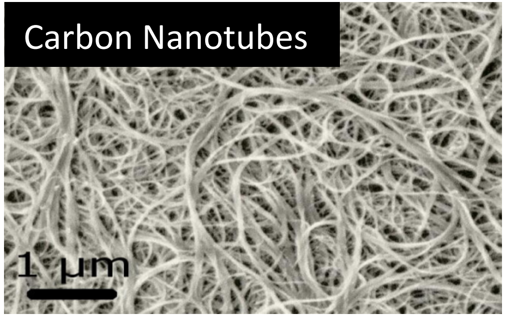


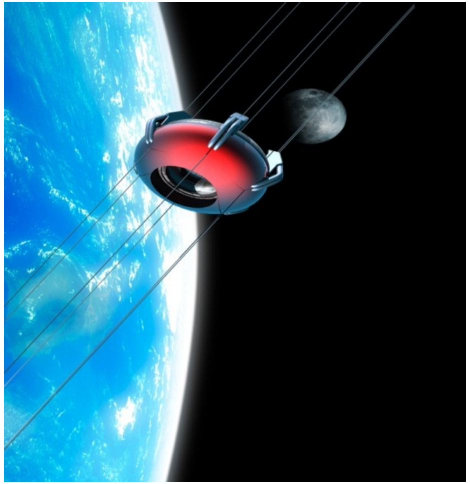
Nanomaterials: *different kinds of stuff*











Images from the Colvin Lab, Creative Commons

Nanotechnology: A Paradigm Shift

In Nanotechnology, what is important about materials is NOT really what they are made of, but how small they are. This is different than every other materials age in human history.

Your Three Take-Homes

Week 1, Lecture 2, Nanotechnology

- Nanotechnology: Small, strange and important
- There are diverse perspectives about nanotechnology
- Nanomaterials are NanoX – where X can be anything

History of Nanotechnology

Week 1, Lecture 3

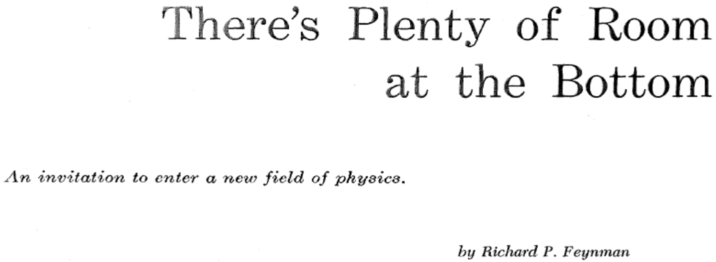
- Nanotechnology was accidental in ancient times
- Origins of the field are in manufacturing
- Politics and nanotechnology – and the HYPE factor

Ancient Nanotechnology?

St. Vitus Cathedral (built 1364)

Pre-1980s: people who made materials did “nano” but didn’t know it

Feynman and the Bottom 1960s and 1970s


There's Plenty of Room at the Bottom

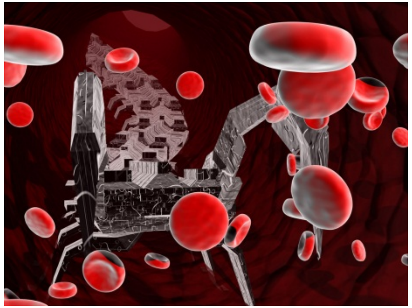
An invitation to enter a new field of physics.

by Richard P. Feynman


Richard Feynman
Creative Commons

- **Richard Feynman** – "Why can we not write the entire 24 volumes of the Encyclopedia Brittanica on the head of a pin?" http://resolver.caltech.edu/CaltechES:23.5.1960Bottom
- **Professor Norio Taniguchi** did ultraprecision manufacturing & credited with first using the term 'nanotechnology'

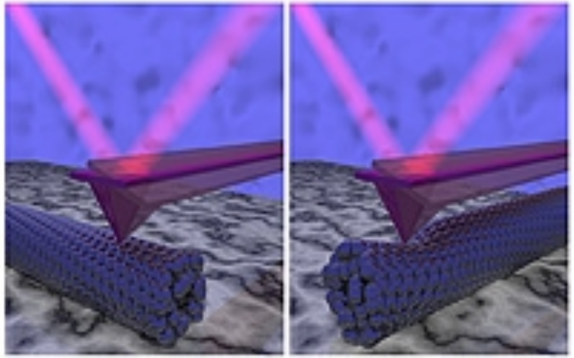
Nanotechology or SciFi? The 1980s



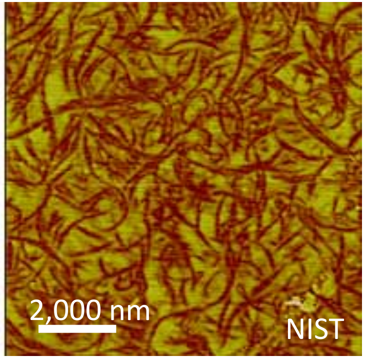
- Drexler ‘Engines of Creation’ – book about assembling matter
- Nanoscale robots, assembled machines, fantastic science fiction

Under resources – see debate between Rick Smalley and Eric Drexler
Fat fingers – sticky finger in C&E News

Nanotechnology: Visualized in the 1990s

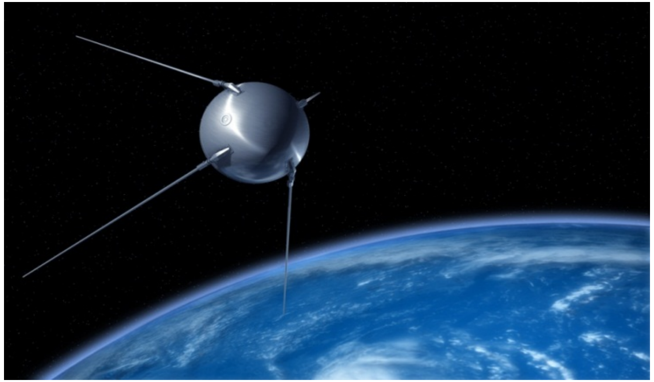


From Christian Klinkel University of Hamburg



1990s: Methods to image and study the nanoscale world ushered in nanotechnology – we did begin to control matter precisely

Nanotechnology and Global Politics ?!

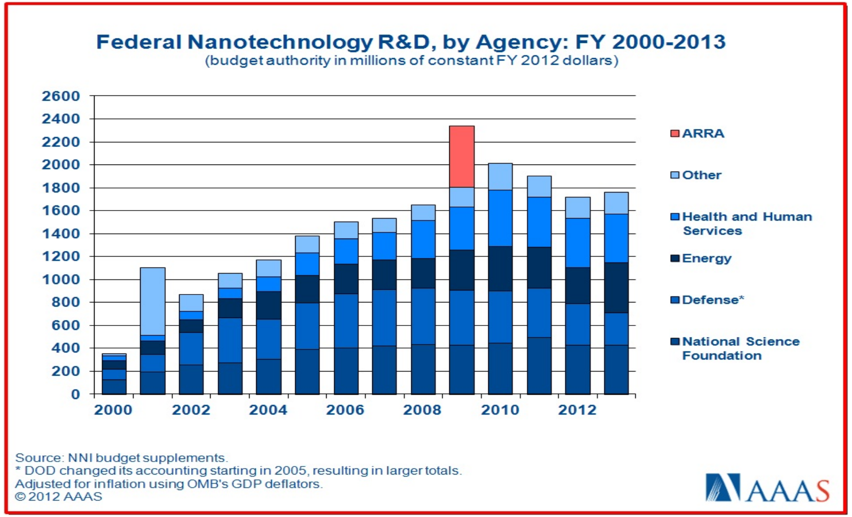


Do you know what this object is?

OK do you know now?

The Nationalization of Nanotechnology

WWW.NANO.GOV



U.S. R&D investment in nanotechnology

More than 15 billion dollars in research dollars

Investments relative to other countries closely scrutinized

The HYPE Factor and Nanotechnology

'Hype': to promote or publicize a produce or idea often exaggerating its importance or benefits

1.00
Trillion
by 2015!

US NSF

2.9
Trillion
by 2014

LUX research

http://www.nanowerk.com/spotlight/spotid=1792.php

DM Berube, Nano-Hype the Truth Behind the Nanotechnology Buzz

Your Three Take-Homes

Week 1, Lecture 3, Nanotechnology

- Nanomaterials have been used for centuries, but not rationally
- It took a village: scientists, futurists, politicians, industry
- Nanotechnology is political and its hype can draw criticism

Nanotechnology Right NOW

Week 1, Lecture 4

- Nanotechnology is enabling to most industries
- There are examples right NOW of nanotechnology
- Most transformative applications still in the future

Nanotechnology: An Enabling Technology

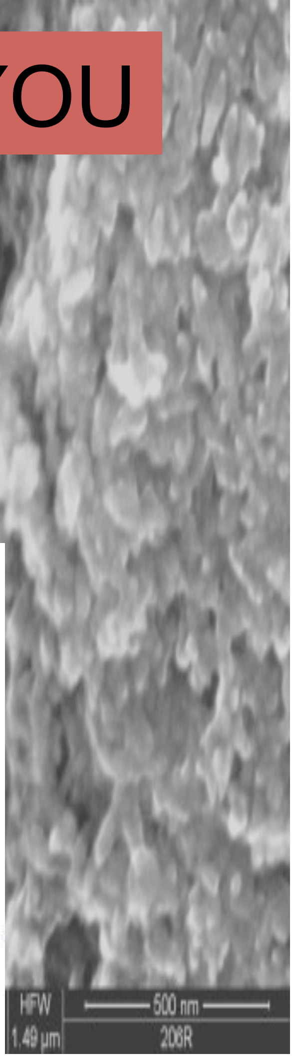
Nanotechnology

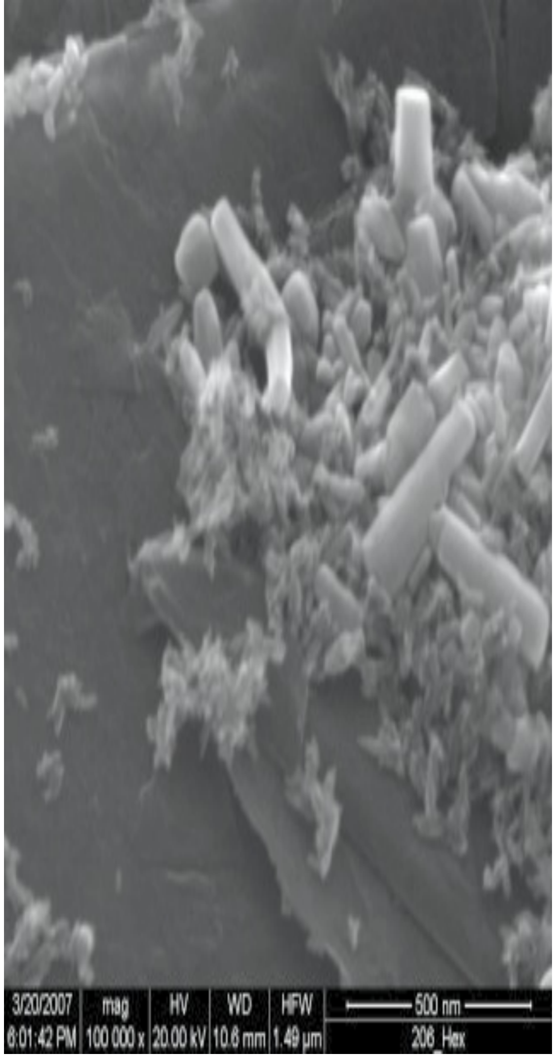
- Paintable Batteries
- Faster computers
- Better water filters
- Less Polluting Factories
- Lighter Automobiles
- Self-cleaning clothing
- Personalized Medicine
- New Cancer Treatments
- Smart Textiles
- Permanent Vitamins
- More bandwidth
- Stronger Tennis Rackets

Nano is Now…

Product	"Nano Inside"	Value Added
	Active Ingredient: Nanoscopic TiO_2/ZnO	Transparency
	Active Ingredient: Carbon Nanotubes	Strength and Bounce
	Embedded with "Nano Whiskers"	Stain- and Wrinkle-Resistance

Nano is ON YOU





Nanomaterial-containing products: a web exercise

http://www.nanotechproject.org/cpi/browse/nanomaterials/carbon-nanotube/

Have some fun and search on carbon nanotubes: What is it with sports equipment!

Try fullerene – yes there are people who EAT nanomaterials

Your Three Take-Homes

Week 1, Lecture 4, Nanotechnology

- Nanotechnology ENABLES other technologies
- You probably use nanotechnology in your daily life
- Most people think more is ahead of us than behind us

Why go SMALL?

New Worlds for Materials

Lecture 5, Week 1 Nanotechnology

- Converting size units mathematically in the metric system
- Materials in the 'nano' world – between chemistry and biology in size
- Small size means that nanomaterials can interact with biological and enivronmental systems in new ways

Why go Small?
New Worlds

Wikipedia, fair use

Gulliver's Travels

How Small is Small in Nanotechnology?

Nanotechnology is the application of materials with dimensions from **about** 1 to 100 nanometers!

The Meaning of a Nanometer

10^{-2}m = 1 centimeter (cm)
10^{-3}m = 1 millimeter (mm)
10^{-6} m = 1 micron (um)
10^{-9} m = 1 nanometer (nm)
10^{-10} m = 1 angstrom (A or Å)

"nano" comes from the Greek word 'Dwarf'

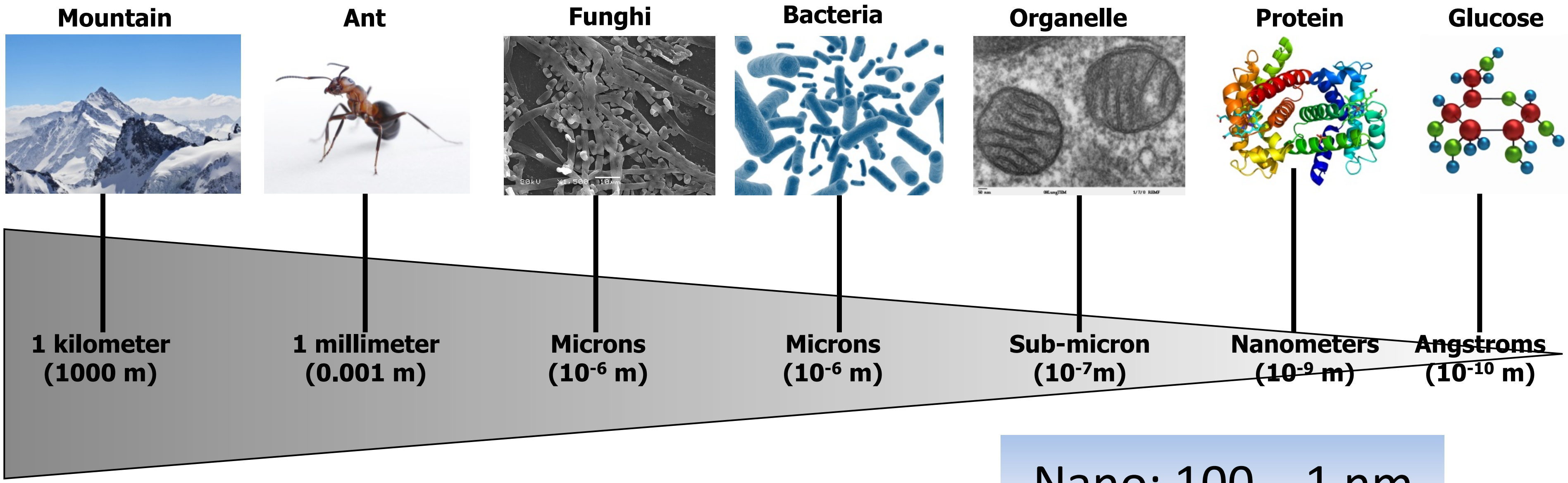
<u>Example 1:</u> How many nanometers are in one meter?

1 ~~meter~~ · 1nm/10^{-9} ~~meter~~ = 1,000,000,000 or one billion or 10^{9} nm

<u>Example 2:</u> If something is 10 nm in diameter, what is its diameter in centimeters?

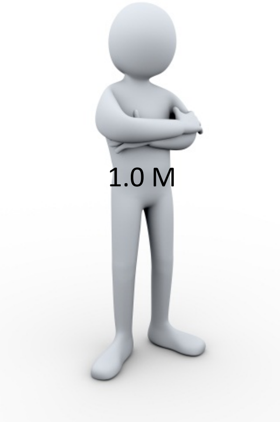
10 ~~nanometers~~ · 10^{-9} ~~m~~/1 ~~nanometer~~ · 1cm/10^{-2} m = 10^{-6} cm

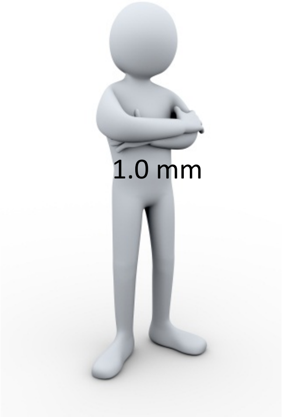
What does 10 nm mean?

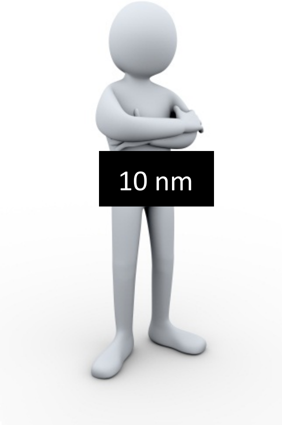


Nano: 100 – 1 nm

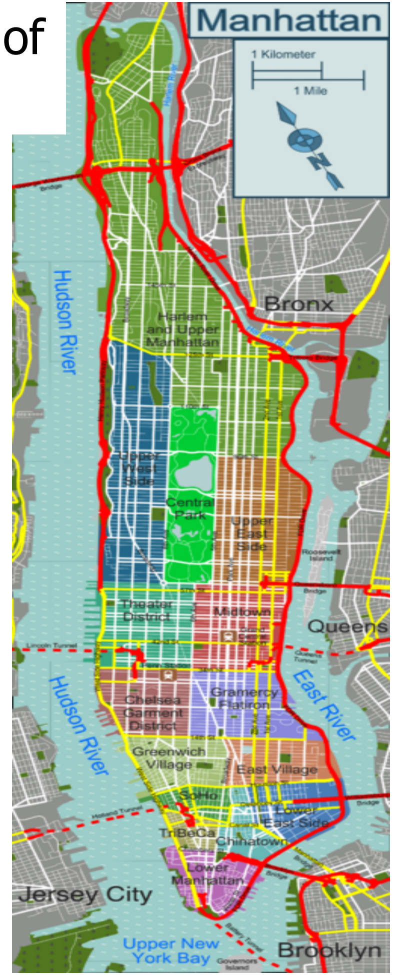
Shrinking to the Nanoworld



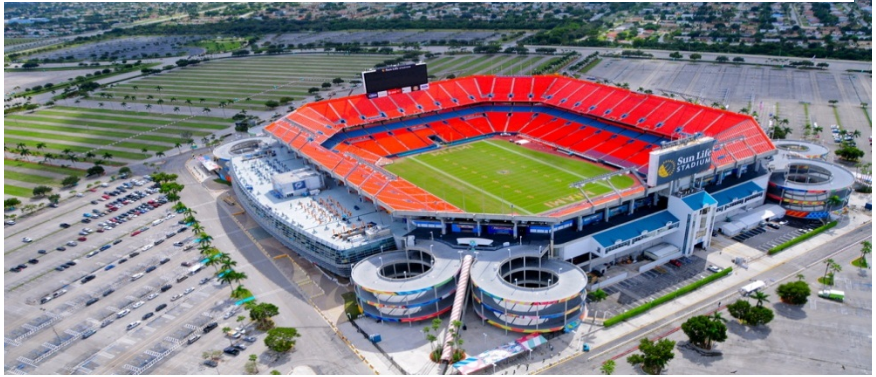


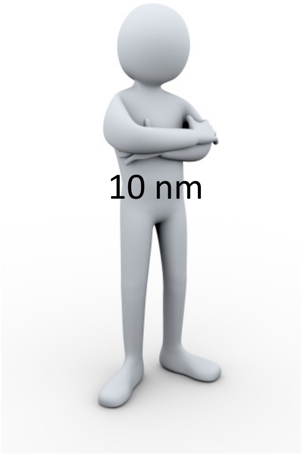


A human hair is like the island of Manhattan

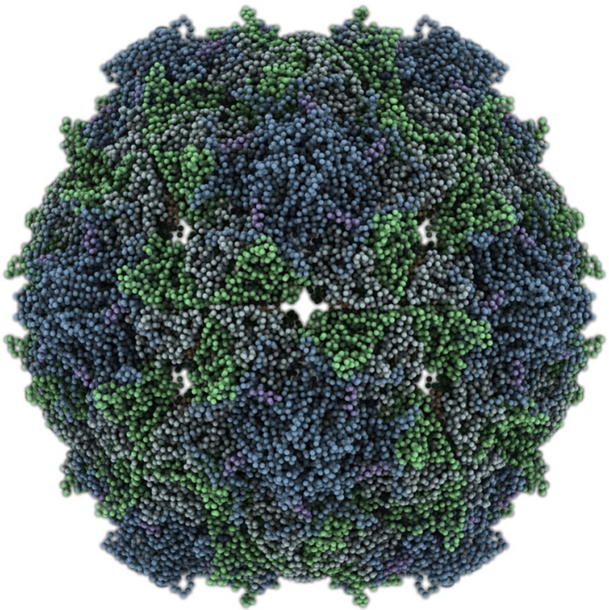


A red blood cell is like a soccer stadium

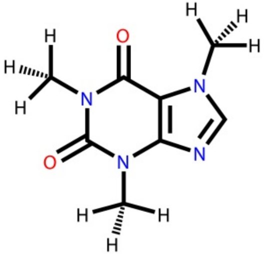




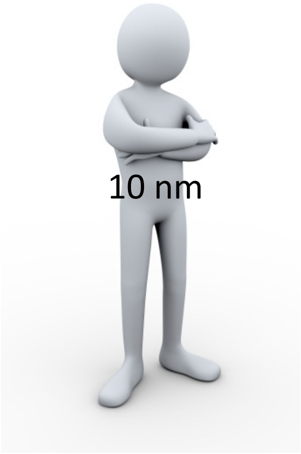
Basketball hoop= polio virus



Hydrogen atom = ping pong ball

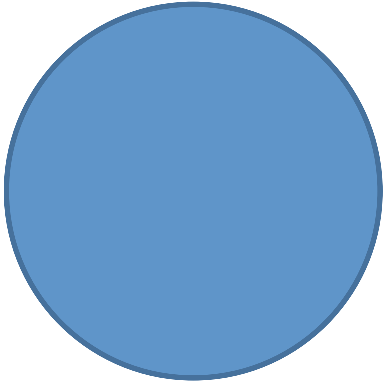


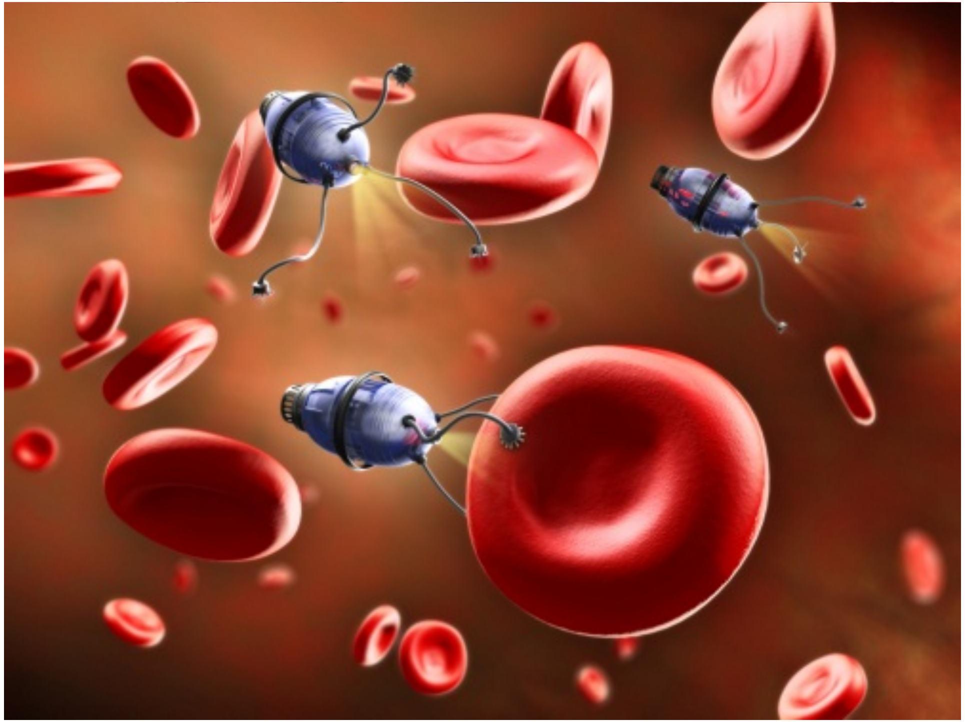
Caffeine= baseball



Chair = small protein

Nanomaterials in Biology
A New World





The "ideal" size for nanoparticle biodistribution into tumors is about 100 – 200 nm diameter

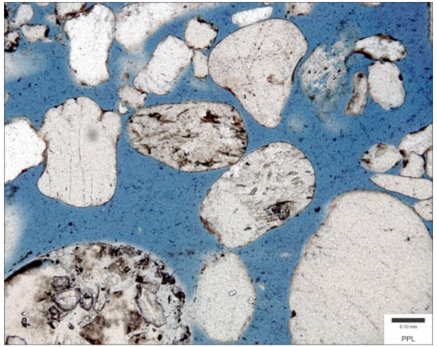
We can inject nanoparticles and they can kill tumors

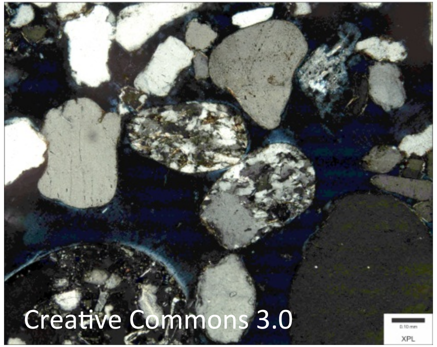
Nanomaterials in our Environment: *A New World*

Nanoparticles can move through many types of rocks (e.g. sandstones)

Want nanoparticles to be ten times smaller than the 'pore throat"

Nanoparticles can be injected into formation to enhance imaging and literally help us 'see' deep underground





Your Three Take-Homes

Week 1, Lecture 5, Nanotechnology

- Nanomaterials: larger than molecules, smaller than biomolecules
- Because of their size, they can ‘get into’ organisms and environmental samples.
- Being nanosized opens up new worlds for materials

Why go SMALL? GEOMETRY

More stuff, more surface

Lecture 6, Week 1 Nanotechnology

- Simple geometry tell us what happens as objects get small
- You get more objects in the same volume, or weight, as you go small – more bang for your buck
- You get more surface area in the same volume, or weight, as you go small – and surface is where the action is

Smaller Grains: More ‘objects’

1 quartz crystal

1 thousand trillion grains of sand

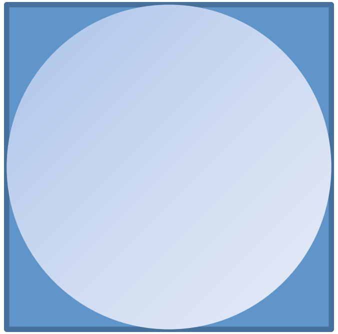
Small = Greater Numbers
The Fruit Demo

The data (in about 500 gm)

Grapefruit	1
Oranges	3
Lemons	6
Key Limes	22

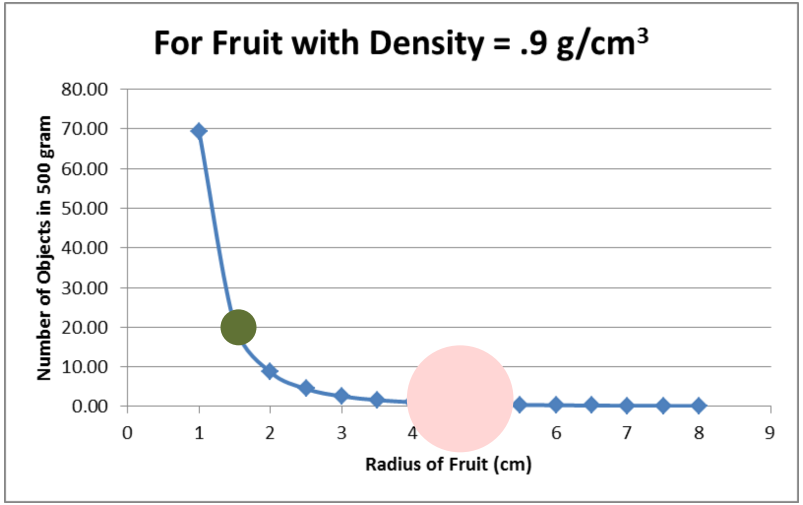
Numbers Increase with the CUBE of Radius

Number in 1 gram = 1 g · (1 cm^3/1g) · (1 object/8R^3)



$V_{fill} = (2R)^3$

$V_{obj} = 4/3\,\pi\, R^3 = 1.333\pi\, R^3$



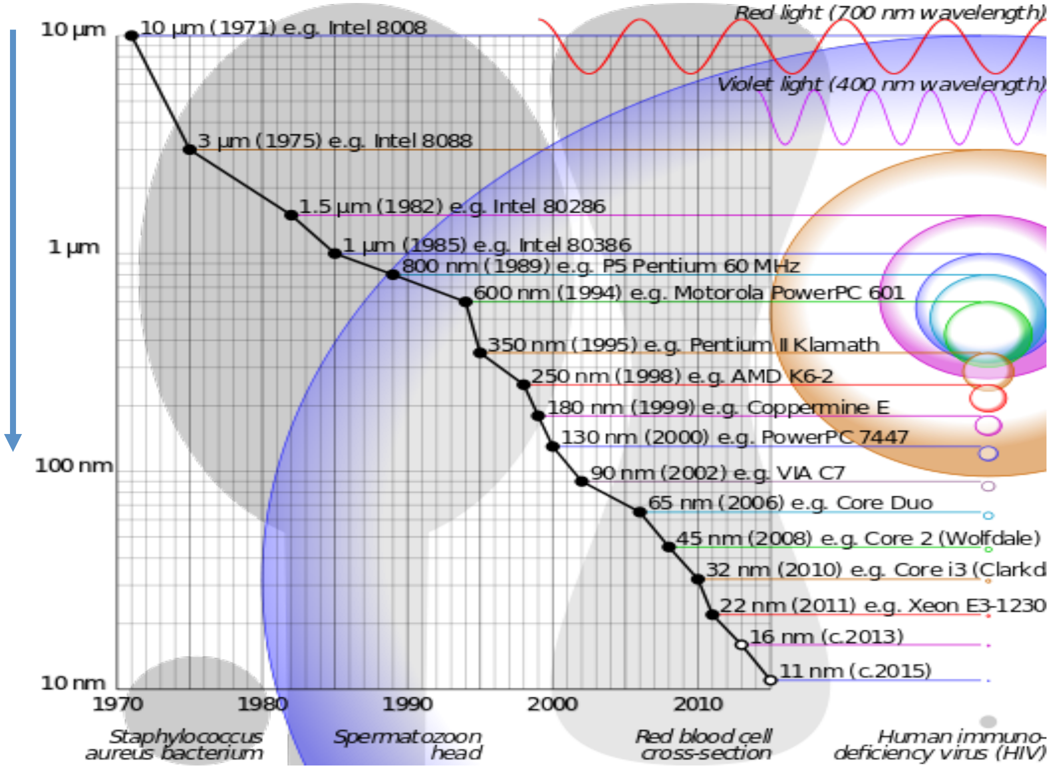
As r gets small
Number increases

If you reduce radius ten times

Get a THOUSAND fold increase in number

Smaller Things = More Devices

If we have devices with 100 times smaller feature sizes we have $(100)^3$ or one million more devices



Wikimedia, Creative Commons from Cmglee

Smaller Grains: More surface

1 quartz crystal

1 thousand trillion grains of sand

Surface Area Increases with the 1/Radius

Number in 1 gram · Surface area of one object =

$1\ g \cdot (1\ cm^3/1g) \cdot (1\ object/8\ R^3) \cdot 4\pi R^2/1object = 1/R$

$SA_{object} = 4\pi(R)^2$

If you reduce radius ten times → Get a tenfold increase in surface area

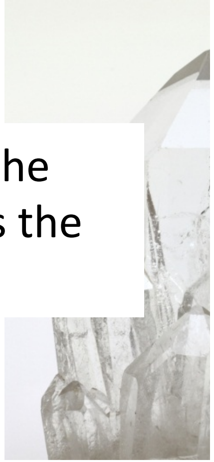
500 grams of limes, 1 nm in radius, would have the surface area of several city blocks!!!

Surfaces: Where the Action Is!

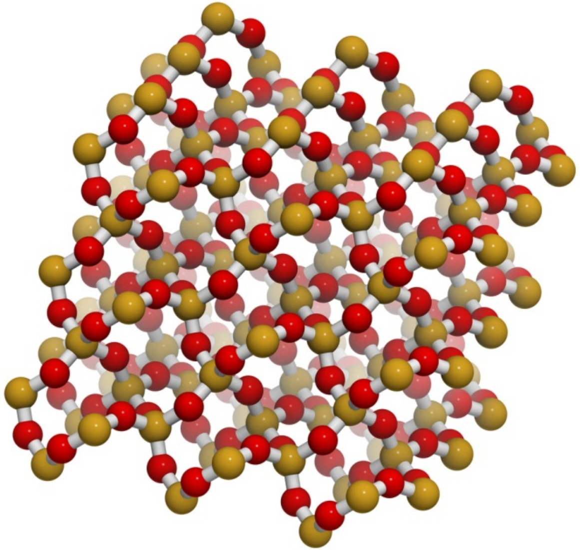
Catalysts that remove pollutants in your car → all about surface area

Filters for water depend on the surface of activated carbon – more surface longer lifetime

Smaller Grains: More 'objects'



This means the density stays the same



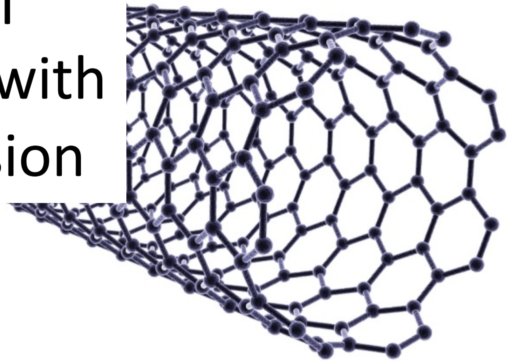
Molecular structure of quartz is the same 'nanosized' as it is in the bulk

1 quartz c

grains of sand

Important Caveat: Nanomaterial Structure

Density is NOT always constant with material dimension



Bulk Carbon

Nanoscale Carbon

Your Three Take-Homes

Week 1, Lecture 6, Nanotechnology

- As you shrink the size of any object: get more of them – goes as inverse radius cubed!
- As you shrink objects: get more surface area – depends inversely on radius
- This argument is strictly geometric! Does NOT depend on what the material is made of (e.g. FRUIT = SILICON = CARBON) if the arrangement of atoms stays the same (e.g. density is size independent)

Why go SMALL?

Materials Get Different

Lecture 7, Week 1 Nanotechnology

1. Materials CAN get very different in their properties when their size gets very small

2. The exact dimensions of 'different behavior' vary between materials and properties of interest

3. Examples of size-dependence in nanoscale materials are the color of quantum dots, the reactivity of gold, and the structure of carbon

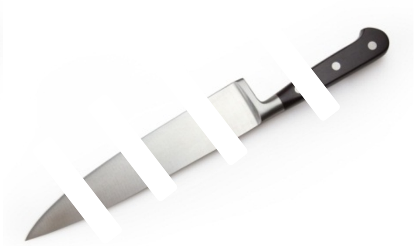
Nanomaterials: THEY ARE STRANGE

Size matters! Micro-dog could become nano-cat

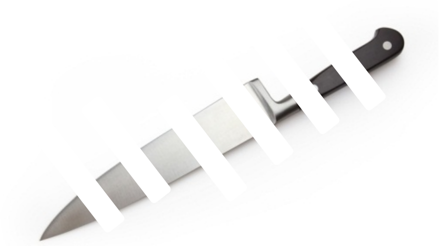
Getting Smaller

The magic size?

If you cut a knife
in half



And then in
half again



And then in
half again,
and again,….

When is it no longer a knife?

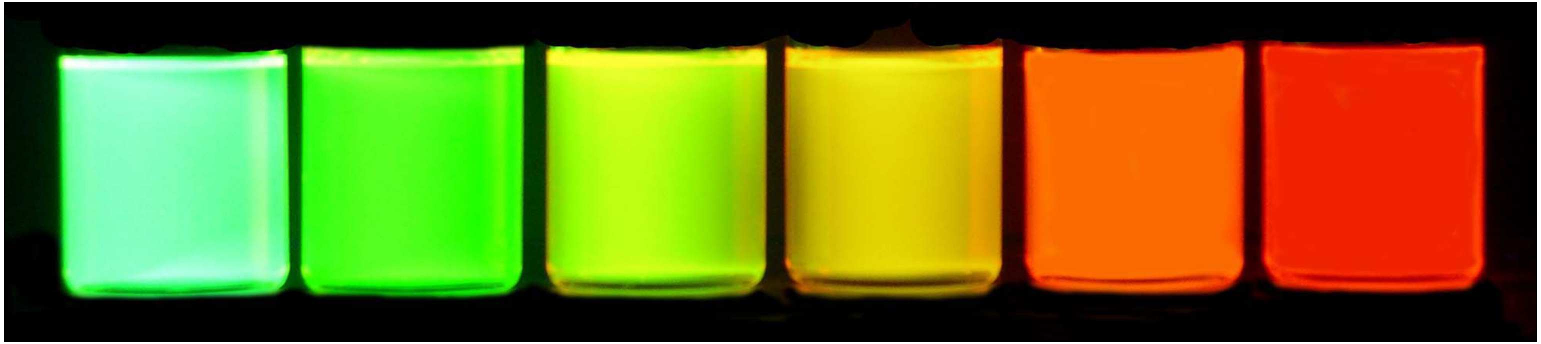
A) As soon as you cut it once
B) When the knife can no longer cut anything
C) When the knife is too small to be held by a person
D) Never, it will always have a 'knifelike' identity

Many Types of Material Properties to Consider

	NanoX	NanoY
Optical		
Magnetic		
Mechanical		
Electrical		
Catalytic		
Sorptive		

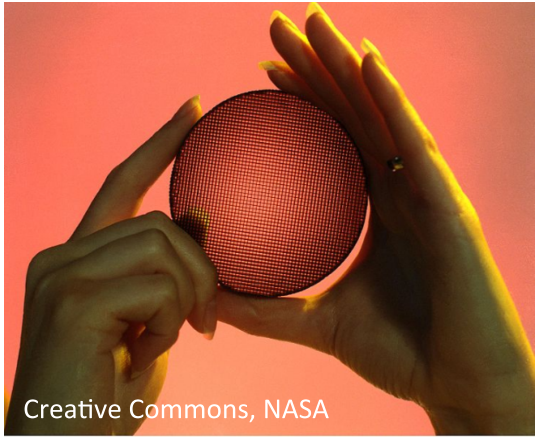
The importance of 'size' to a material depends on what property you care about

Example 1: Quantum Dots
Optical Properties



3 nm   6 nm

Example 2: Reactive Gold



$2CO + O_2 \rightarrow 2CO_2$

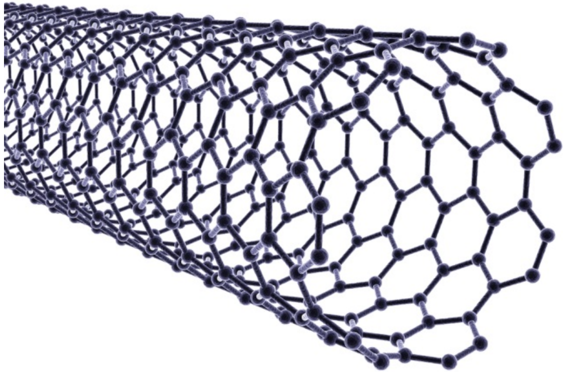
- Discovery of gold catalysis in nanoscale clusters (1986)
- Selective oxidation of hydrocarbons, CO for industrial processes
- Best when sizes are well under 3 nanometers

Haruta, M., *Gold Bull.* **2004,** 37, 27

Example 3: Carbon

Structural Properties

Bulk Carbon



Nanoscale Carbon

Your Three Take-Homes

Week 1, Lecture 7, Nanotechnology

- Materials don’t just get smaller, they CAN get different
- “Unique” nanoscale behavior is associated with transformative technologies
- This is very materials dependent! FRUIT ≠ SILICON ≠ CARBON

ONE BIG TAKE-HOME: We go small to explore new worlds, get more objects and surface area, and to make materials act totally differently from their bulk counterparts

The Nanotechnology ZOO

Part 1

Lecture 8, Week 1 Nanotechnology

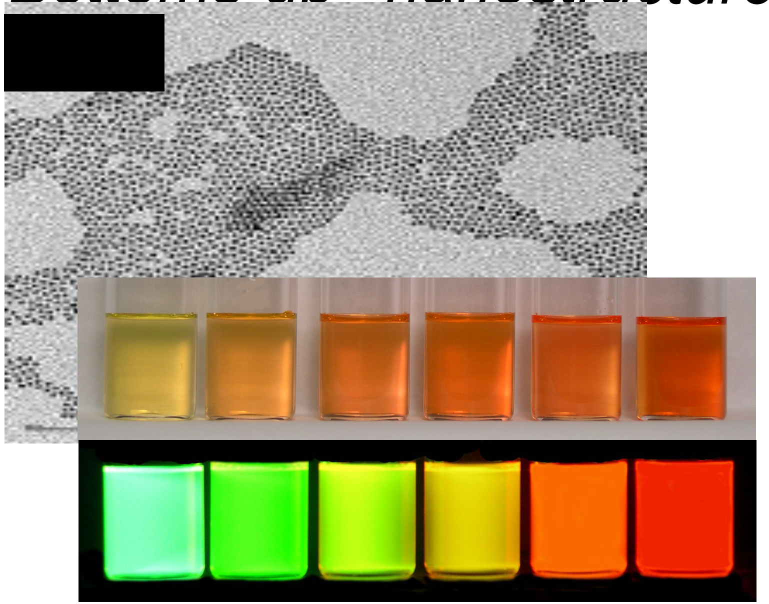
- Anything can be nano - NanoX

- A few broad classes of materials

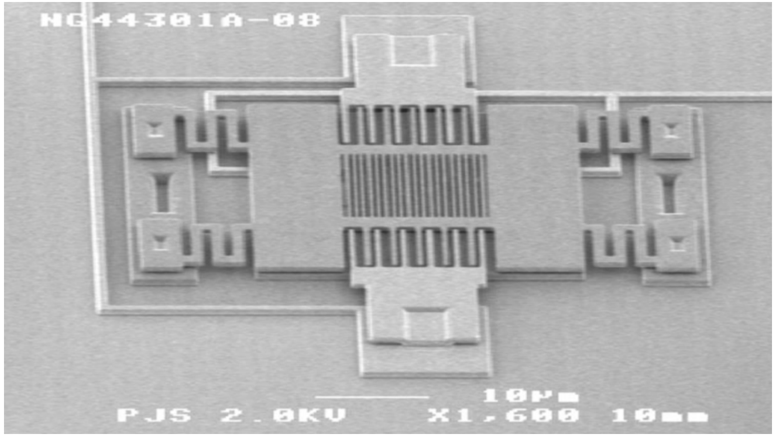
- First: Nano-semiconductors, nano-metals

Nanotechnology = nanomaterials

"Bottoms-up" nanostructures



"Top-down" nanostructures



CREDIT: Keeler, Sandia National Laboratory.
A grating to study fine movement.

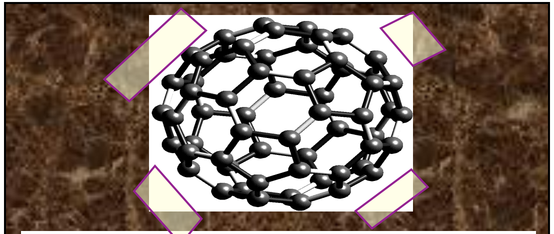
Remember this?

Anything can be NanoX

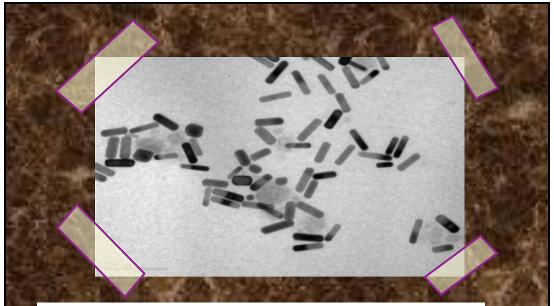
Group→ ↓Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo

Lanthanides	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinides	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

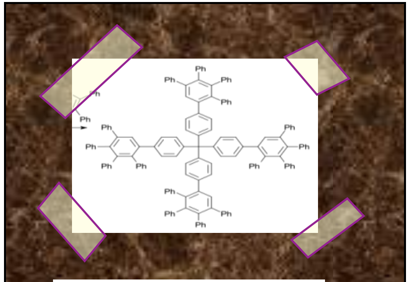
Today: A Guided Tour



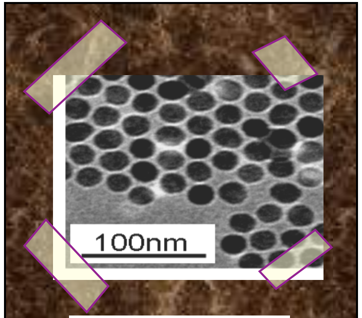
Carbon Nanostructures



Metal Nanoparticles



Dendrimers



Ceramics

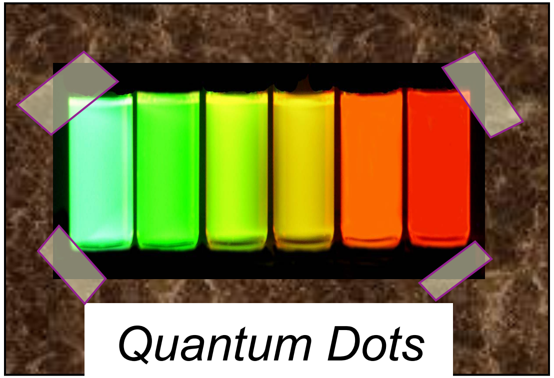
Quantum Dots

NEXT

Carbon, Dendrimers: Creative Commons 3.0; Metal nanoparticles: em-lab.berkeley.edu; Quantum Dots, Ceramics: Colvin Lab

Quantum Dots

(e.g. Semiconductor Nanocrystals)



<u>What?</u> Nanosized semiconductors
<u>Who sells?</u> Small companies, $$$
<u>When?</u> Mid-1980s, classic systems
<u>How?</u> Liquid phase & Lithography
<u>Formats?</u> In solution, deposited films, embedded in devices

Key concept: Quantum Confinement

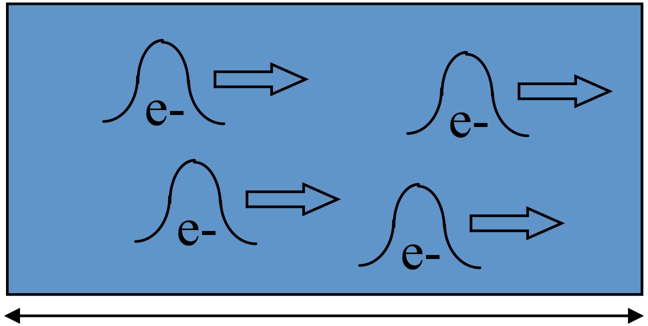
Quantum Confinement

When you make a string shorter, what happens to its sound?

Electron waves in smaller spaces have greater/lesser energy??

Electron waves in smaller spaces are more likely to decay by recombination.

Color of semiconductors – electron waves



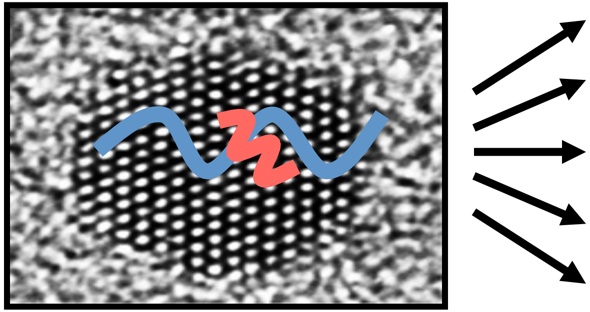
3 inches across

Charges in semiconductors are a certain "size": they are really waves.

Semiconductor	Size of Electron Waves
Silicon	~ 20 nm
CdSe	~ 6 nm
Gallium Arsenide	~ 10 nm

WHAT WILL HAPPEN IF YOU MAKE THE SUBSTANCE SMALLER?

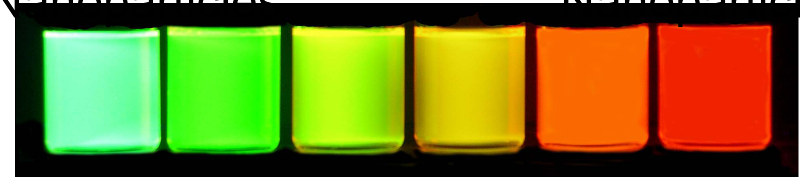
Size Dependent EMISSION: Big Win



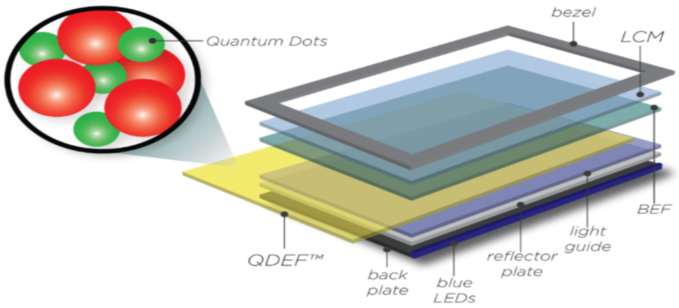
- Tunable color (size)
- Higher quantum yields
- Little photobleaching

3 nm Nanoparticles

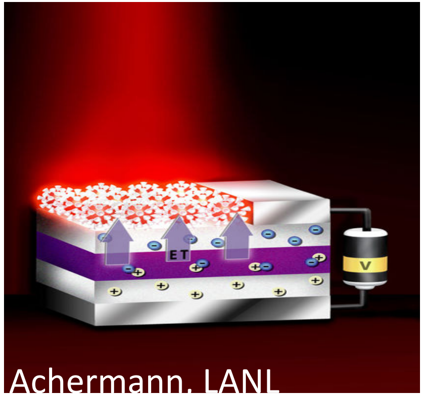
6 nm Nanoparticles



Quantum Dots: Why?



Creative Commons 3.0/nanosys



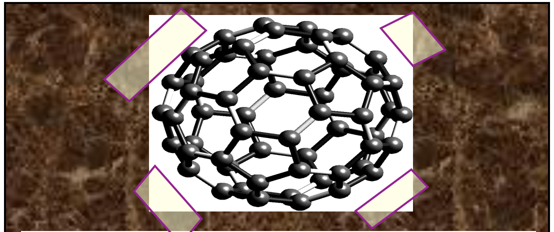
Biological labeling, better lightbulbs, efficient LEDs

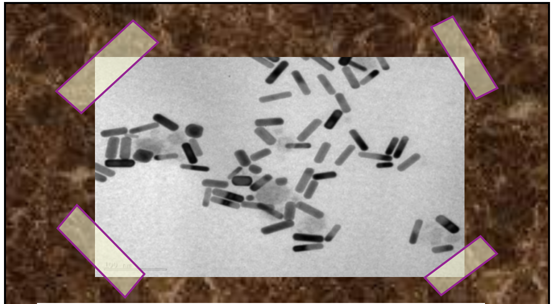
The Stand-Out Features of Nanomaterial Types

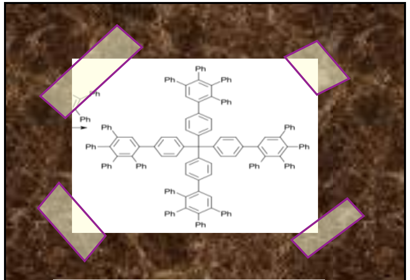
	Quantum Dots	Metals	Ceramics	Carbons	Organic
Optical	★★★				
Magnetic					
Mechanical					
Electrical	★★				
Catalytic					
Sorptive	★				

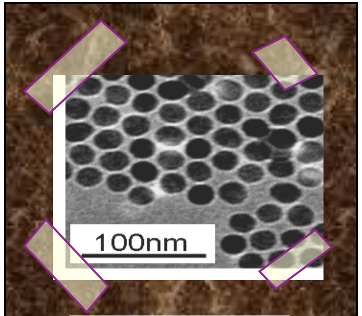
What was weird about semiconductors on the nanoscale? What use is their being small?

Today: A Guided Tour


Carbon Nanostructures


Metal Nanoparticles


Dendrimers



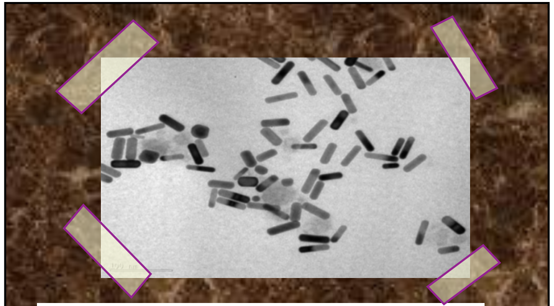
Ceramics

NEXT


Quantum Dots

Carbon, Dendrimers: Creative Commons 3.0; Metal nanoparticles: em-lab.berkeley.edu; Quantum Dots, Ceramics: Colvin Lab

Metal Nanostructures



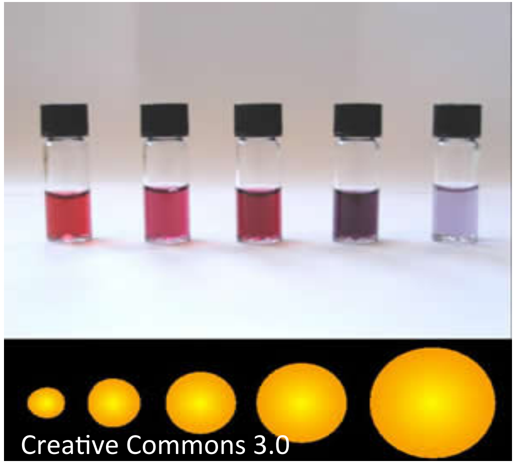
Metal Nanoparticles

What? Nanosized metals
When? Oldest nanomaterial !
How? Liquid, gas phase bottoms-up
Formats? In solution, deposited films, embedded in devices

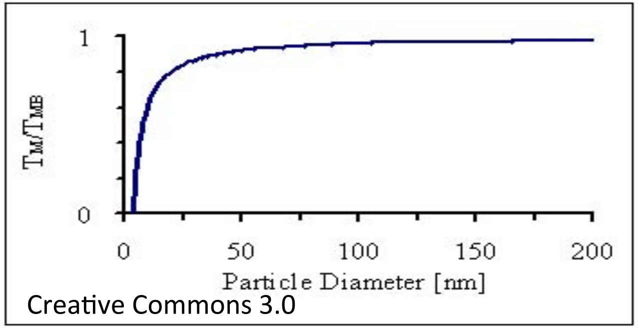
Examples of material composition:

Noble metals: Au, Ag, Pd, Pt ….
Others: Co, Ni, ….

Metal Nanoparticles: Why?



Optical properties vary with size



Melting point decreases with size (gold)

1. Aluminum – explosives
2. Molecular electronics, sensing, electrodes
3. Catalysts for selective oxidation

The Stand-Out Features of Nanomaterial Types

	Quantum Dots	Metals	Ceramics	Carbons	Organic
Optical	★★★	★★			
Magnetic		★			
Mechanical					
Electrical	★★	★★			
Catalytic		★★			
Sorptive	★				

Your three take-home messages

Week 1, Lecture 8, Nanotechnology

- Materials don’t just get smaller, they CAN get different
- This is very material-dependent! FRUIT ≠ SILICON ≠ CARBON
- Many different materials: a VERY broad field

The Nanotechnology ZOO

Part 2

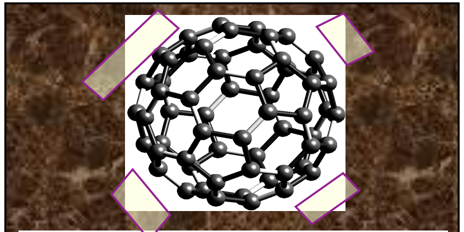
Lecture 9, Week 1 Nanotechnology

- Continuing the tour through the zoo…

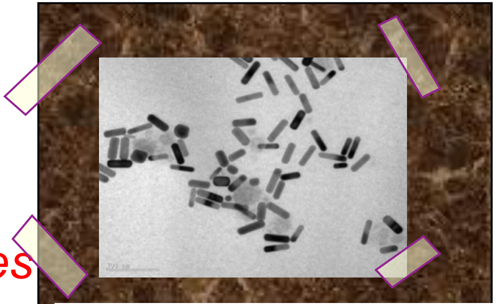
- Nano-ceramics

- Nano-carbon

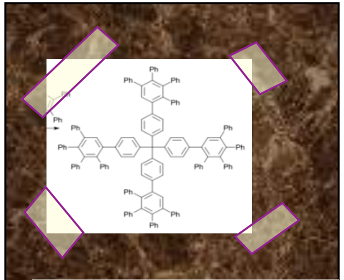
Today: A Guided Tour



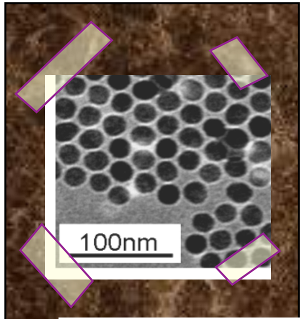
Carbon Nanostructures



Metal Nanoparticles



Dendrimers



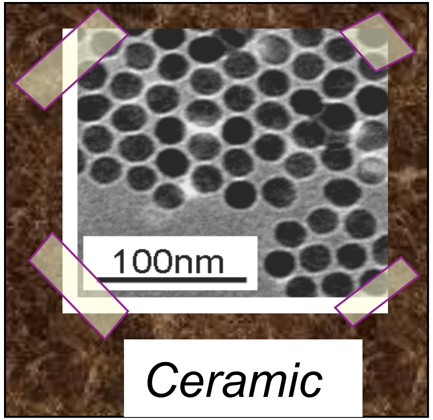
Ceramics

NEXT

Quantum Dots

Carbon, Dendrimers: Creative Commons 3.0; Metal nanoparticles: em-lab.berkeley.edu; Quantum Dots, Ceramics: Colvin Lab

Ceramics (e.g. oxides)



Ceramics

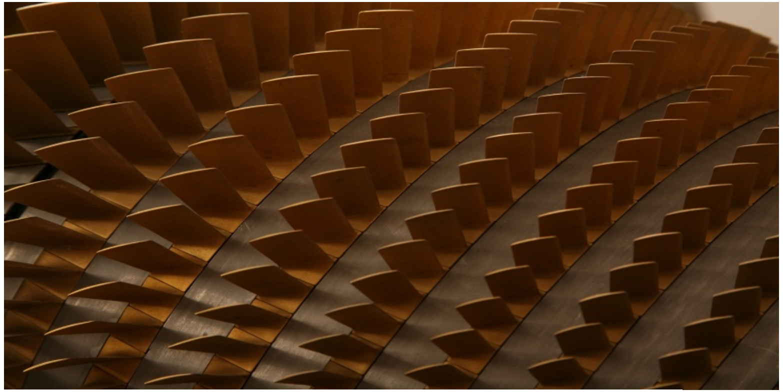
<u>What?</u> Nanosized oxides
<u>When?</u> Mid-1980s, classic systems
<u>How?</u> Liquid and gas phase
<u>Formats?</u> Deposited films, elements in nanocomposites

Examples of material compositions:

TOO MANY TO LIST!!

Iron oxides, Maganese oxides, Titanium dioxide ….

Nanoceramics: Why?



nanoZrO_2: Protecting turbines

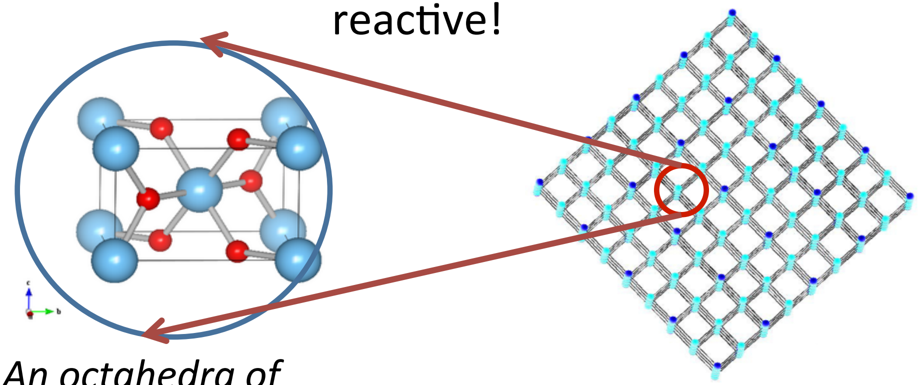
nanoTiO_2: Self-cleaning glass

1. Catalysis – photocatalysis of titania
2. Magnetic materials
3. Super strong and plastic coatings

Titania: The Material

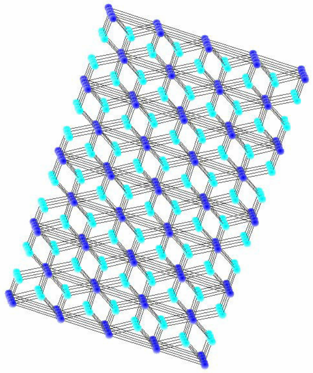
Rutile TiO_2: a mineral

Ti-OH at the surface of anatase: reactive!



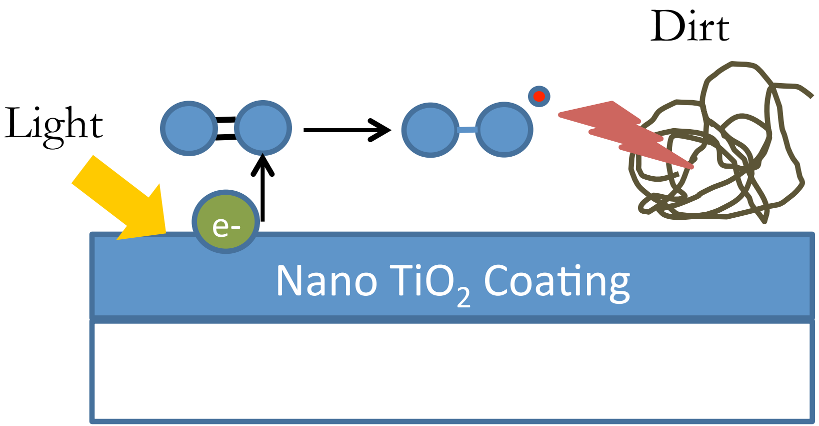
An octahedra of Titanium and Oxygen

Anatase:Photoactive



Rutile: Inert

Mechanism for Cleaning



Does the high surface area of nanotitania help or hurt this application?

Why does the surface eject an electron upon absorption of light?

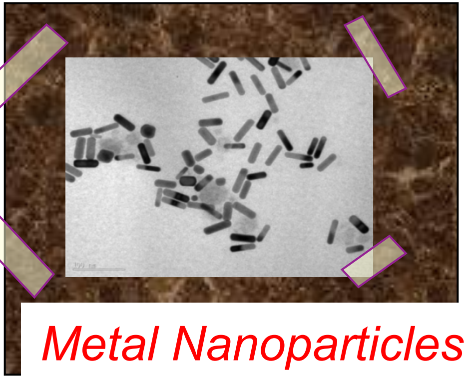
The Stand-Out Features of Nanomaterial Types

	Quantum Dots	Metals	Ceramics	Carbons	Organic
Optical	★★★	★★	★		
Magnetic		★	★★★		
Mechanical			★★		
Electrical	★★	★★			
Catalytic		★★	★★		
Sorptive	★				

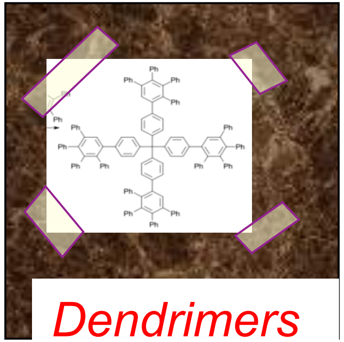
Today: A Guided Tour

Carbon Nanostructures

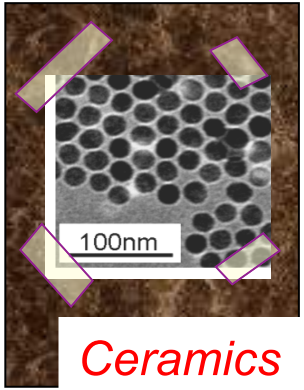
NEXT



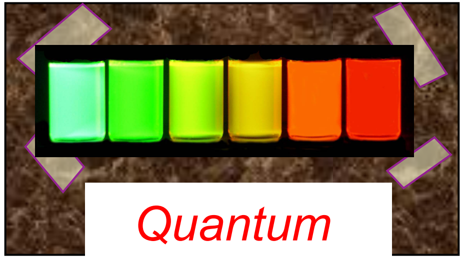
Metal Nanoparticles



Dendrimers



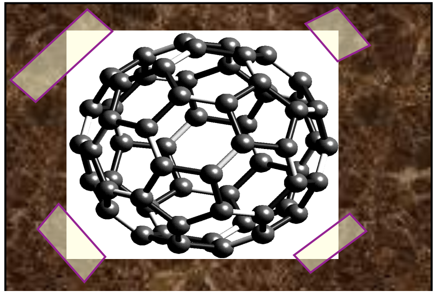
Ceramics



Quantum Dots

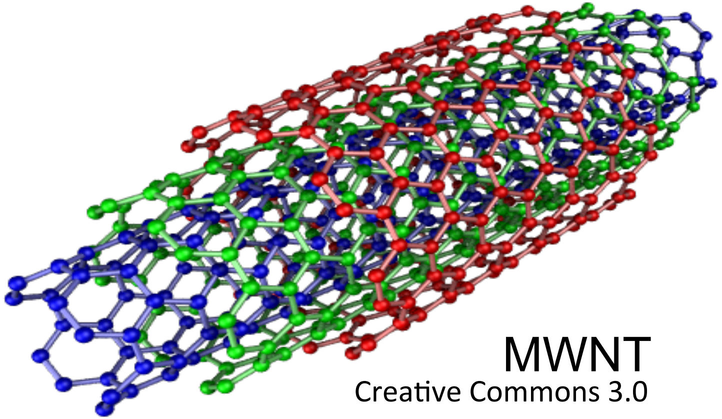
Carbon, Dendrimers: Creative Commons 3.0; Metal nanoparticles: em-lab.berkeley.edu; Quantum Dots, Ceramics: Colvin Lab

Carbon Nanostructures

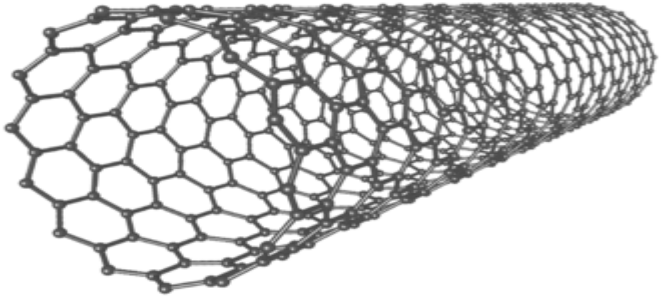


What? Nanosized carbons
When? Mid-1980s, classic systems
How? Gas phase
Formats? In solution, deposited films, embedded in devices

Carbon Nanostructures

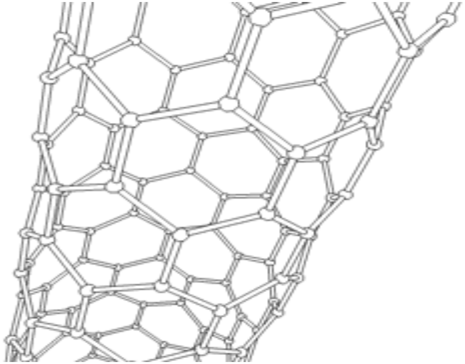


MWNT



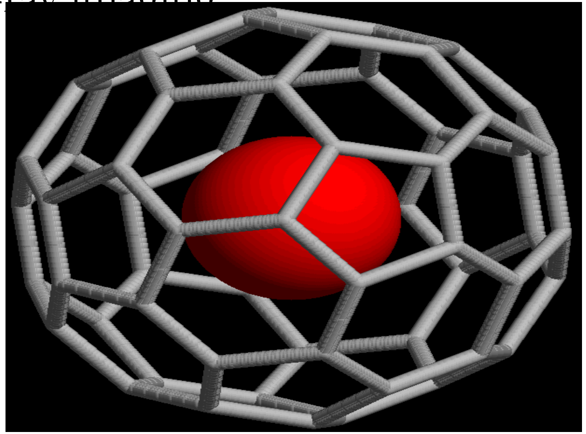
SWNT

Carbon Nanostructures: Applications



Carbon nanotubes as one-dimensional wires

A buckyball encapsulating a metal atom –contrast agents for MRI or x-ray imaging

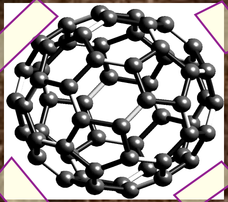


Source: Wikimedia Commons

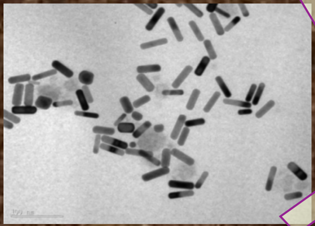
The Stand-Out Features of Nanomaterial Types

	Quantum Dots	Metals	Ceramics	Carbons	Organic
Optical	★★★	★★	★	★	
Magnetic		★	★★★		
Mechanical			★★	★★★	
Electrical	★★	★★		★★★	
Catalytic		★★	★★		
Sorptive	★			★★	

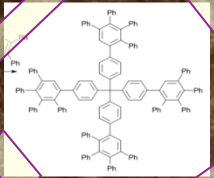
Today: A Guided Tour



Carbon Nanostructures

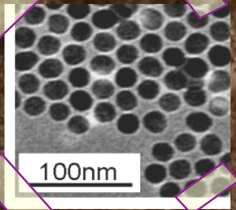


Metal Nanoparticles



Dendrimers

NEXT

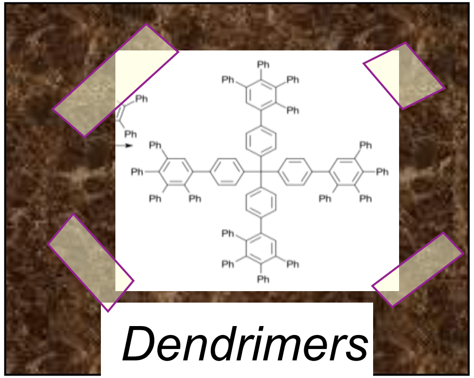


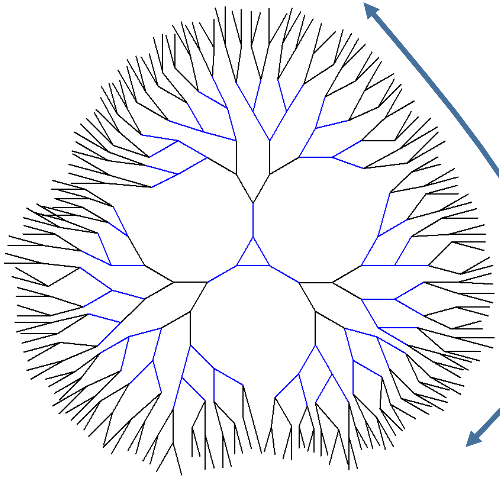
Ceramics

Quantum Dots

Organic Nanostructures

<u>What?</u> Nanosized polymers
<u>When?</u> Mid-1980s, classic systems
<u>How?</u> Polymer synthesis
<u>Formats?</u> Solution, deposited films





A christmas tree for decorating with drugs, targeting agents

Applications: drug delivery, gene delivery, encapsulation of other nanoparticles

	Quantum Dots	Metals	Ceramics	Carbons	Organic
Optical	★★★	★★	★	★	
Magnetic		★	★★★		
Mechanical			★★	★★★	★★
Electrical	★★	★★		★★★	
Catalytic		★★	★★		
Sorptive	★			★★	★★★

Sizes and critical sizes (in nm)

	Lower end size	Higher end size	Critical size for nanomaterial to be different than bulk
Quantum dots	1 nm	15 nm	~ 15 nm for CdSe, emission
Metals	1 nm	100 nm	100 nm for Au, scattering
Ceramics	2 nm	50 nm	~ 40 nm for magnetic (H_c)
Carbons	.7 nm	2 nm	*- all different, structure -*
Organics	1 nm	100 nm	*Size dependence only S/V*

<u>Generally</u> true for isolated nanoparticles produced in bottoms-up methods

Your three take-home messages

Week 1, Lecture 9, Nanotechnology

- Size matters: properties change on the nanoscale
- This is very materials dependent! FRUIT ≠ SILICON ≠ CARBON
- Nano-ceramics (metal oxides), nano-carbon, nano-polymers