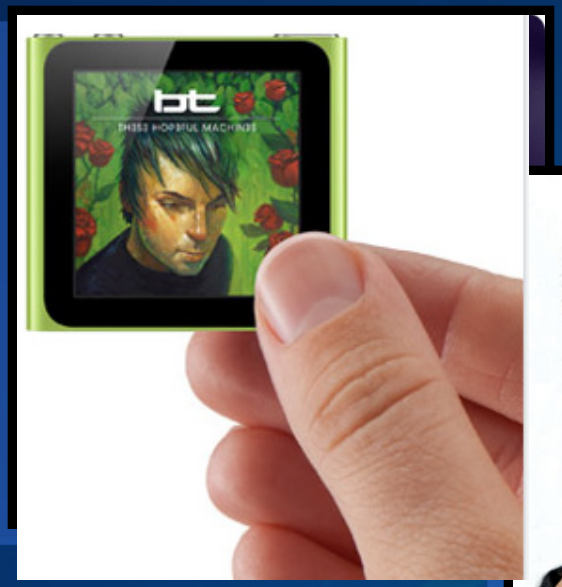
Electronics and Computing

- Electronics
- Cell Phones
- MP3 players
- Computers

By Jeanne Nye, Andrew Greenberg, Ph.D., Zeeshan Yacoob, and Angela Jones, Ph.D.

From Computers to Cellphones, GPS to Bluetooth, Wi-Fi to Smartcards.



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http://www.apple.com/ipodnano/design.html

Image Source:
http://www.beststuff.com/images/articles/112106a1.jpg

Image Source:
http://images.photogallery.indiatimes.com/photo.cms?msid=2074380 GPS

How can small science help us communicate across big distances?

What is nanotechnology?

A description -

- Nanotechnology is the understanding and control of matter at dimensions between approximately 1 and 100 nanometers, or nanoscale.
- Unusual physical, chemical, and biological properties can emerge in materials at the nanoscale. These properties may differ in important ways from the properties of bulk materials and single atoms or molecules.
- Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale.

Note: This slide and the next 9 slides are the same for all research areas.

Resource: www.nano.gov

How BIG is nano?

Macrosize
meters, decimeters, centimeters, millimeters

Child


A child is about 1 meter tall
1 meter = 1,000,000,000 nm
(1 billion nanometers)

Hand

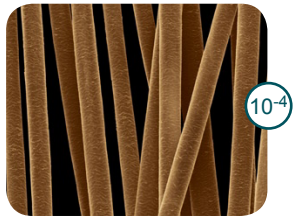

A hand is about 1 decimeter wide
1 decimeter = 100,000,000 nm
(100 million nanometers)

Pinky Finger


A pinky finger is about
1 centimeter wide
1 centimeter = 10,000,000 nm
(10 million nanometers)

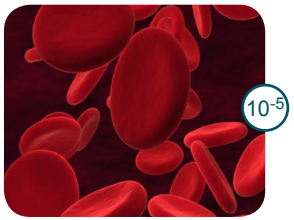
Freckle


A freckle is about 1 millimeter wide
1 millimeter = 1,000,000 nm
(1 million nanometers)

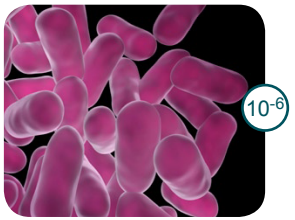
Strand of Hair


A hair is about one tenth of a
millimeter wide
0.1 millimeter = 100,000 nm
(100 thousand nanometers)

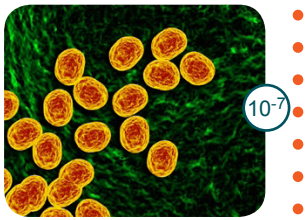
Microsize
micrometers

Red Blood Cell


A red blood cell is about
10 micrometers wide
10 micrometers = 10,000 nm
(10 thousand nanometers)

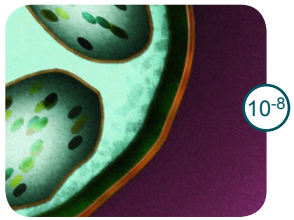
Bacteria


A bacterium is about
1 micrometer wide
1 micrometer = 1,000 nm
(1 thousand nanometers)

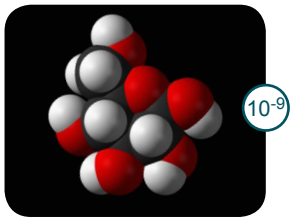
Virus


A viron is about one tenth
of a micrometer wide
0.1 micrometer = 100 nm
(1 hundred nanometers)

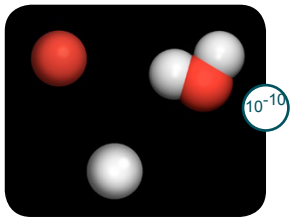
Nanosize
nanometers

Cell Membrane


A cell membrane is about
10 nanometers wide
10 nanometers = 10 nm

Sugar Molecule


A sugar molecule is about
1 nanometer wide
1 nanometer = 1 nm

Atom


An atom is about one tenth
of a nanometer wide
0.1 nanometer = 0.1 nm

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Emily Maletz graphic design
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Accompanying book available for purchase at www.lulu.com

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Nanoscale

1 nanometer =

1 billionth (10^{-9}) of a meter

D

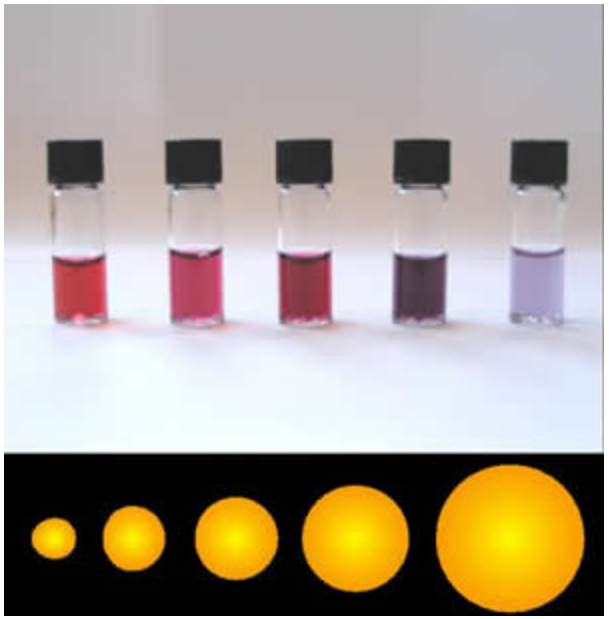
a marble

10^9 D

Why do we care?

Things behave differently at this scale

- Quantum mechanics plays a much more important role
- For example,
  - A brick of gold is shiny and “gold”-colored.
  - A vial of gold nanoparticles in solution can be a range of colors depending on the size of the nanoparticles.
  - This is because of a phenomenon know as quantum confinement.



Suspensions of discrete (separated) gold nanoparticles in clear solution vary in color from pink to purple as the nanoparticle size gets bigger.

Image source: “Causes of Color”, WebExhibits, http://www.webexhibits.org/causesofcolor/9.html

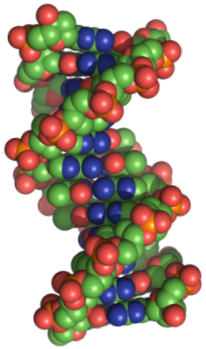
Why else do we care?

This is the scale of biological processes

- Human cells and bacteria have diameters around 1-10 *micro*meters

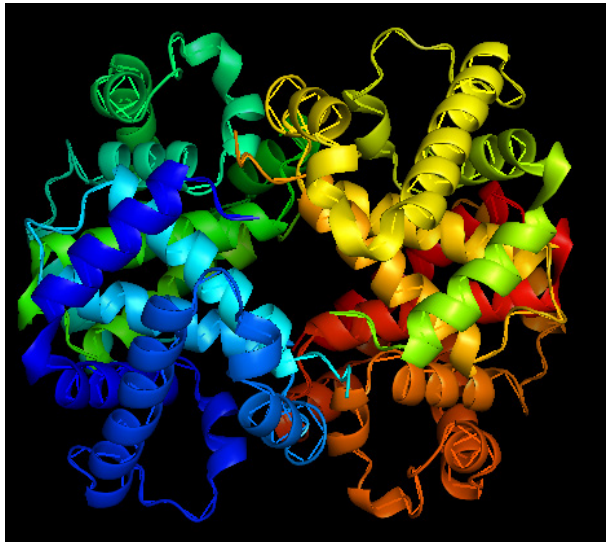
BUT

- Cellular machinery is on the *nano*scale
  - Diameter of DNA is ~2 nanometers
  - Hemoglobin, the protein that carries oxygen through the body, is 5.5 nanometers in diameter



Structure of DNA

PDB ID: 1BNA



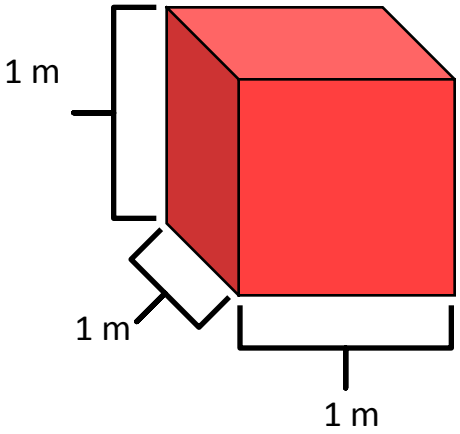
Structure of hemoglobin

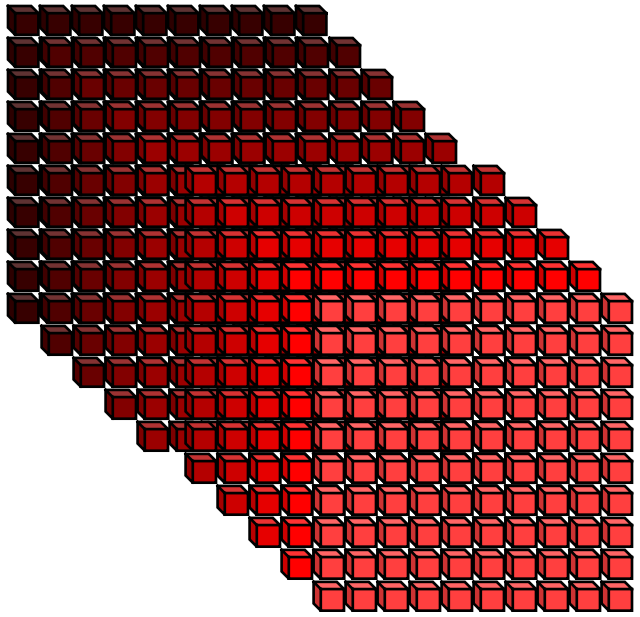
PDB ID: 1BUW

One more reason: surface area

Another reason nanomaterials behave differently from bulk materials of the same chemical is because of surface area – or the area of an object that is an exposed surface.

For this cube, each edge is 1 meter in length.





For these cubes, each edge is 0.1 meters in length, but there are 1000 cubes.

Volume (in cubic meters): **1m X 1m X 1m = 1 m^3**

(0.1m X 0.1m X 0.1m) X 1000 cubes = 1 m^3

Surface Area (in square meters): **(1m X 1m) X 6 sides = 6 m^2**

(0.1m X 0.1m) X 6 sides X 1000 cubes = 60 m^2

Surface Area and Reactions

- This increased surface area allows chemical reactions to go much faster.
- Think about it this way:

  Which dissolves faster in your coffee or tea, a sugar cube or a teaspoon of granulated sugar?

Answer: Granulated sugar

Nano-enabled Consumer Products

As of the March 10, 2011, there are over 1300 consumer products around the world that are manufacturer-identified as nanotechnology-based.

- Touch screens (iPhone)
- Sunscreens
- Cosmetics
- Tennis rackets
- Bicycles
- Fabric
- Computer memory
- Many more…

These products are here, ready to buy today!

Resources: The Project on Emerging Nanotechnologies website: http://www.nanotechproject.org/

Activity Description

- You have been assigned an area of nanotechnology research to support.
- Go through this presentation and any other credible sources to identify three benefits of research in nanotechnology toward your area of interest and up to three potential risks you perceive in your area of interest.
- As a group, we will weigh the risks and benefits of each area to decide how much of our federal nanotechnology budget should go to each research area.

Disclaimer: this is a contrived scenario

- There are no federal nanotechnology budget cuts
  - $1.7 billion estimated for FY2012 (fiscal year 2012)
  - Increased investment proposed for FY2013 (nearly $1.8 billion)
- Nanoscale Science, Engineering and Technology (NSET) subcommittee of the National Science and Technology Council's Committee on Technology is an actual government entity
  - Composed of representatives from 25 federal agencies (NIH, DOE, DOD, etc.)
  - Purpose is to coordinate planning, budgeting, and implementation of the National Nanotechnology Initiative (NNI)
  - These representatives work together to create an integrated federal program.
- Actual nano "budget" is different from what is proposed in this activity
  - Actual "budget" is given as a supplement to the President's 2013 Budget Request submitted to Congress
  - **It represents the sum of the investment in nanotechnology and nanoscience planned for 2013 by federal agencies**
  - The agencies submit how much they are planning to spend on nanoscience
  - In the activity scenario, we're doing the opposite of what the actual NNI Budget represents in that we're distributing a pre-determined amount amongst these research areas.

Resources: NNI Budget website: http://www.nano.gov/about-nni/what/funding

Electronics and Computing

In this presentation, you will learn about some of the developments in nanotechnology in the research areas of electronics and computing

Consider the following when learning about these developments:

1. Might these nanotechnology developments infringe on human rights to privacy and freedom?
2. Is it safe for me? Is it safe for others?
3. Could the use of this nanotechnology development have unwanted and negative environmental effects?
4. What economic impact could the use of this nanotechnology development have on producers, consumers, and other industries? Might they be negative or positive?

What About Your Rights?

If so, are these developments more important than

- Your privacy?
- Your rights as a citizen?
- Your rights as a human being?

Are the answers somewhere in between?

Image source: http://www.info4security.com/Pictures/web/w/v/m/iStock_Law.jpg

Links to outside sources

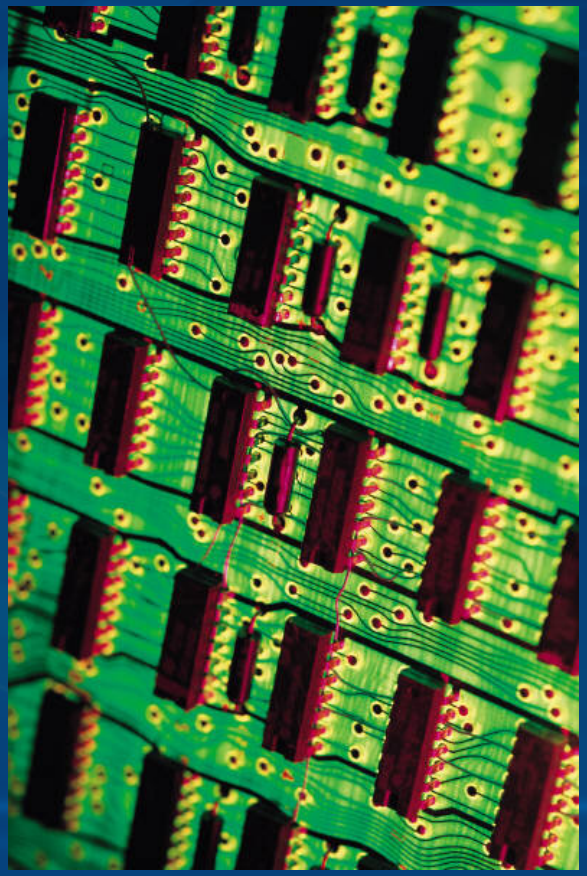
Within this presentation will be many underlined words. If you click on the underlined text, your browser will take you to other websites, videos, or other resources to learn more about what is on the slide.

These links are chosen to give you additional information, but ***these presentations can stand alone***. It is unnecessary to go to the links for the purpose of this activity.

We try to make sure the links are active, but given the ever-changing nature of the internet, you might find a few that take you to a location that is no longer active. Please let the facilitator know if you find an inactive link.

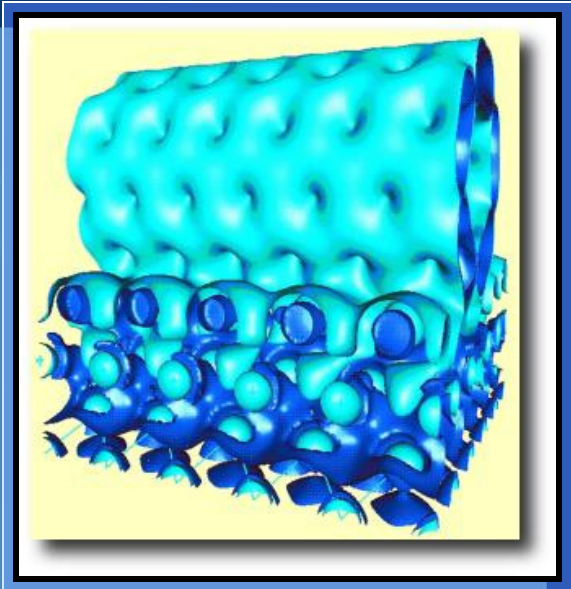
1. Electronics

- How small would you want your digital camera, cellphone and MP3 player?
- Of course, with nanotechnology they will potentially be more precise and faster, too.
- On the next page you'll read about a nano-innovation for transistors, important electronic components.



Nano-Electronics

We all use electronics which are getting more powerful even as they get smaller. This constant increase in computing power is called Moore's Law. Nanotechnology is making sure that Moore's Law continues for generations. Today's transistors are just 100-200 nanometers wide and getting smaller. [1] In 1998, scientists made a transistor from a single carbon nanotube! [2]



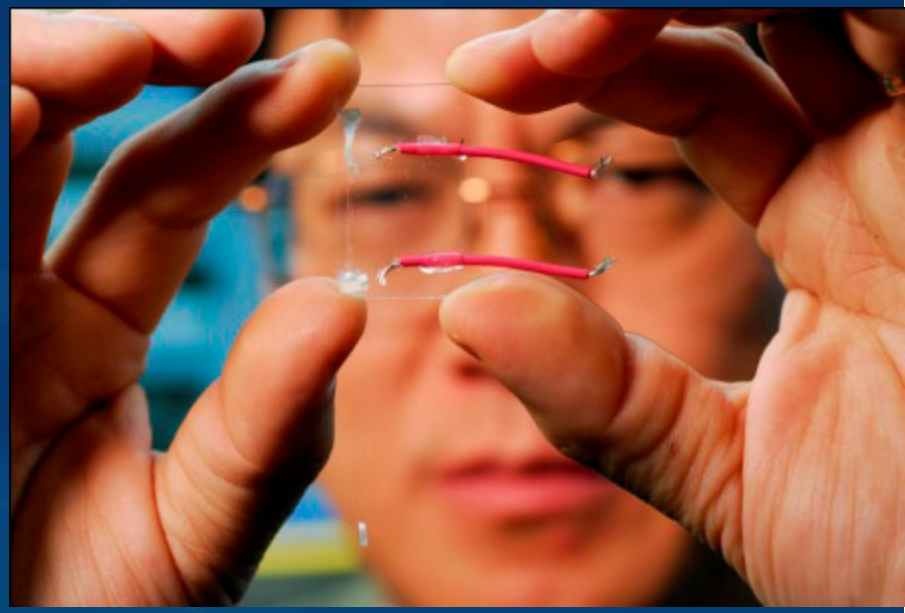
Carbon nanotubes make an electric circuit which is connected to an electrical supply (the dark blue aluminum). [Image Source: NASA].

References: [1] IBM. "IBM Scientists Develop World's Fastest Graphene Transistor" http://www-03.ibm.com/press/us/en/pressrelease/26302.wss

[2] Tans, S. J., A. R. M. Verschueren, and C. Dekker. "Room-Temperature Transistor Based on a Single Carbon Nanotube." Nature 393.6680 (1998): 49-52.

Shirt Power

Imagine fabric that has the ability to generate electricity. It can even recharge portable, wearable electronic devices such as mobile phones, iPods or any other MP3 player that requires a low-level of power. If the fabric is made into a shirt, it could collect power from the sun when the wearer is walking slowly or even from a slight breeze.



Georgia Tech Regents' Professor Zhong Lin Wang holds a prototype microfiber nanogenerator.
Image Credit: Georgia Tech / Gary Meek (ref. 2)

This nanogenerator could definitely be a simple and economical way to generate electricity from physical movements!

References: [1] Weintraub, B., Y. G. Wei, and Z. L. Wang. "Optical Fiber/Nanowire Hybrid Structures for Efficient Three-Dimensional Dye-Sensitized Solar Cells." Angewandte Chemie-International Edition 48.47 (2009): 8981-85.

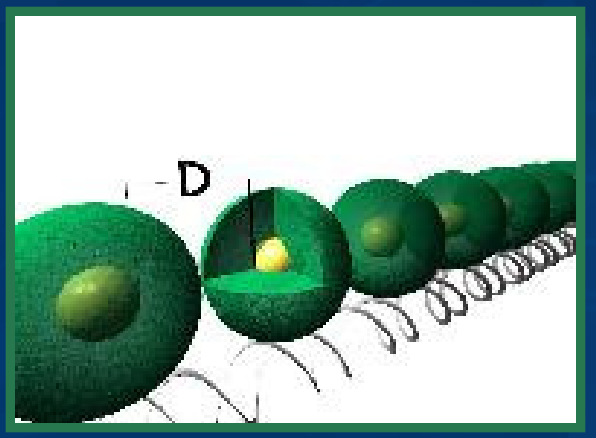
[2] Toon, J., "Fiber-based Nanotechnology Could Power Electronic Devices," Georgia Tech News Release, http://www.nano.gatech.edu/news/release.php?id=1715

Nano-Transistors

"If you think about a structure of gold dots on a DNA strand, it's like a wire with a whole bunch of tiny cuts in it. In order for electrons to travel down a nanoparticle chain, they have to jump or tunnel from one particle to the next. As a result, these nanochains have different properties than a wire would have. That's why you can make transistors out of them." [1]

--- Prof. Jim Hutchinson of the University of Oregon

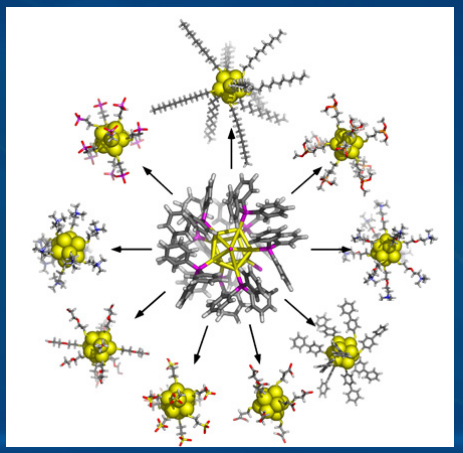
This tunneling behavior, a feature of quantum physics, is a problem for other manufacturing techniques but helps at the nanoscale.



A Nano-Transistor

Gold nanoparticles surrounded by organic, carbon-based, shells self-aligned along a strand of DNA.

[Image Source: from ref. 1]



Gold atom surrounded by thiol-based ligand shell.

[Image Source: Jim Hutchinson Laboratory]

References: [1] Madison, K. University of Oregon. https://scholarsbank.uoregon.edu/xmlui/bitstream/handle/1794/778/IO_2005-04-11.pdf?sequence=3 p 38

And More Gold

Electrical engineers at Berkeley used an ink that contains nano-particles of gold to print the electronic structures.

These can be used for a variety of things:

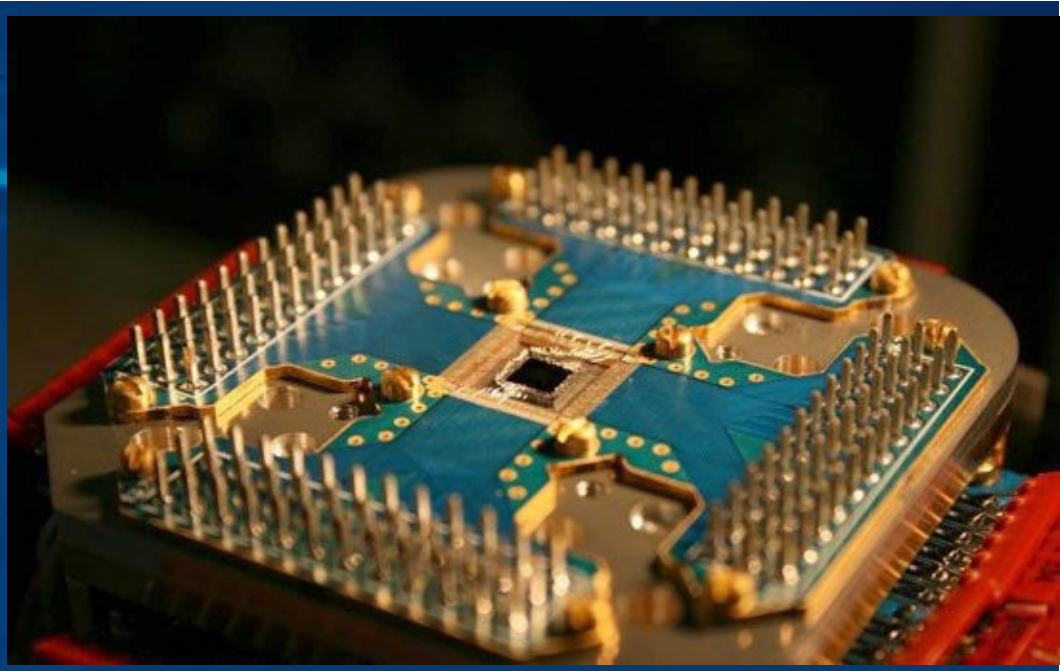
- **Field-effect transistor (Transistors which use electric fields to control conductivity in semi-conductors),**
- **Radio frequency identification (RFID) tags,**
- **Thin-film photovoltaics or flexible sensors.**

Liquid gold synthesized in Subramanian's lab is printed in computer-generated patterns onto the wafer by the inkjet printer to form transistor contacts, wires, inductors, and other components used in RFID circuits.
Photo credit: Peg Skorpinski (ref. 2)

References:
[1] Huang, D., et al. "Plastic-Compatible Low Resistance Printable Gold Nanoparticle Conductors for Flexible Electronics." Journal of the Electrochemical Society 150.7 (2003): G412-G17.
[2] Pescovitz, D., "Will printed circuits replace barcodes on tomorrow's soup cans?," Forefront, http://coe.berkeley.edu/forefront/spring2002/printedcircuits.html

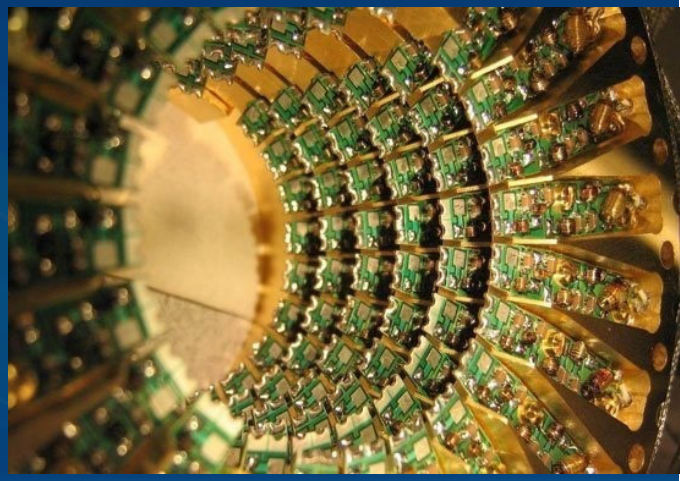
New Chip Technology

Quantum Computer Model. Image Source: from ref. 3



Quantum Computer Model. Image Source: from ref. 3

Scientists are building semi-conductors one atom at a time using magnetism. [1,2]

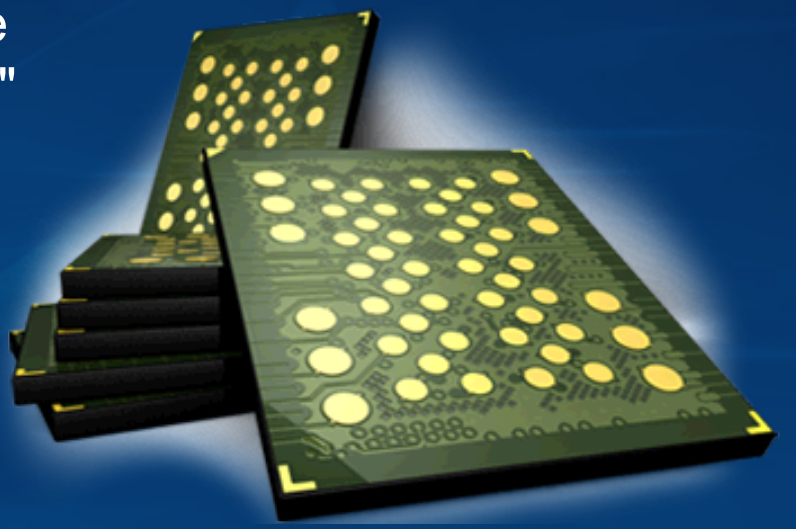


Quantum Computer Model. Image Source: from ref. 3

Resources:
[1] Richardella, A., D. Kitchen, and A. Yazdani. "Mapping the Wave Function of Transition Metal Acceptor States in the Gas Surface Physical Review B 80.4 (2009): 6.
[2] D-Wave. Programmable Magnetic Memory. http://www.dwavesys.com/index.php?page=programmable-magnetic-memory.
[3] Images from: Fast cursor. http://www.fastcursor.com/computers/quantum-computer-photo-gallery.asp

iPod/ iPhone and nanotechnology

- To make the touch-screen on your iPhone work, “Apple uses nanomaterials to "paint" conductive materials such as indium tin oxide onto the surface.” [1]
- The memory is stored on NAND flash memory which relies on advances in nanotechnology to create smaller and smaller chips with more and more memory. [2]
- In April 2011, Intel Corporation and Micron Technology announced a new process of making NAND flash memory, resulting in a 20 nanometer device that holds 8 gigabytes of memory. [3]



NAND Flash memory, Photo credit: Micron Technology.

Watch this video to see what other nano-technological advances can be found in an iPod.

Resources:

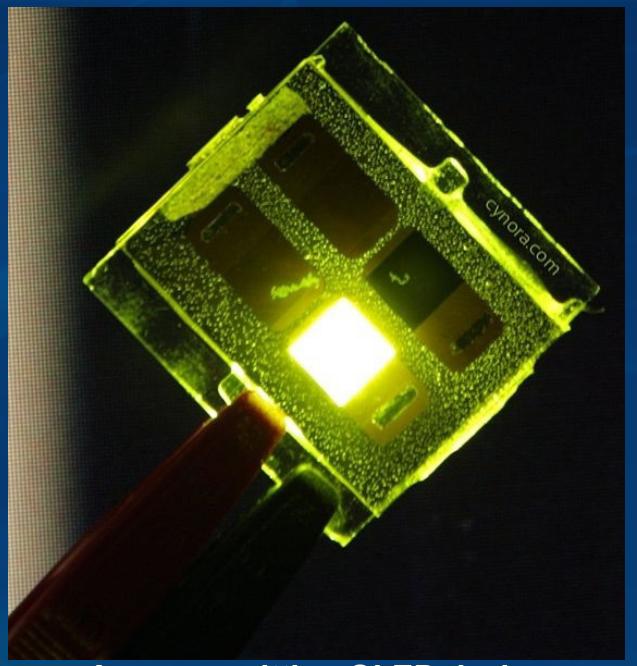
[1] Upbin, B., “From Children's Bladders To The iPhone,” Forbes Magazine, http://www.forbes.com/2007/12/14/nanotech-outlook-conference-tech-cz_bu_1214technano.html

[2] Koprowski, G. "Mac News: iPod: NAND Flash Memory Expanding Beyond iPod nano.", 6 July 2006. http://www.macnewsworld.com/story/51569.html

[3] Intel News Release, “Intel, Micron Extend NAND Flash Technology Leadership, Introduce Industry's Smallest, Most Advanced 20-Nanometer Process,” Intel Newsroom.

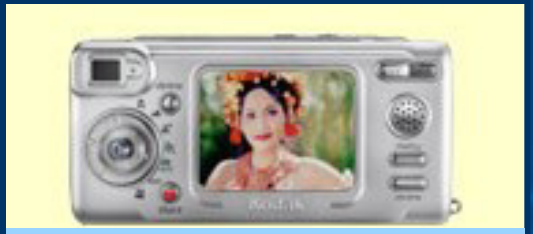
New Displays

- And it's not just the chips inside your computers that use nanotechnology.
- The displays on everything from cellphones to laptops and flat screen TVs are shifting to organic light-emitting diodes (OLEDs), made from plastic films built on the nanoscale. [1]



A green emitting OLED device
Photo credit: Tobias G/ Wikimedia Commons

Look for flexible displays, too! Each pixel is supported by its own transistor. Imagine! Speaking of flexible…



Kodak Easy Share. Image Source: form ref. 1

Resource: [1] DeBoer, C. "Organic LED Displays (OLEDs) - The Next Trend? "
http://www.audioholics.com/education/display-formats-technology/organic-led-displays-oleds-the-next-trend

Talk about Flexible!

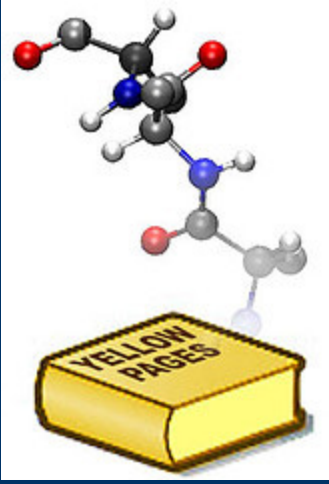


Image Source: from ref. 2

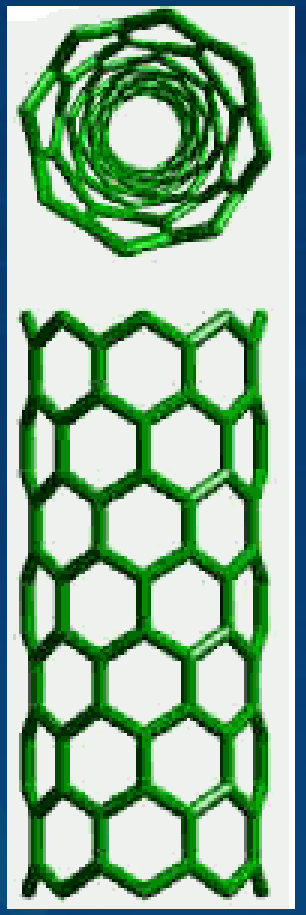
DVD Player. Image Source: form ref. 1

Nanotechnology has made thin, flexible, full-color, electronic paper display screens possible. [1] There could be a lot of advantages to this. No more environmental impact to trees, and distribution costs could be slashed. [2]

References:
[1] Openwave, F. iDSA. “Origami DVD Player”. http://www.idsa.org/content/content1/origami-dvd-player.
[2] Chris. “Could Nanotechnology Save Print Yellow Pages?” http://www.naturalsearchblog.com/archives/2007/03/20/could-nanotechnology-save-print-yellow-pages/

More about Screens

- There are new protective nano-coatings available, super-thin and super-strong. Nanoparticles will enhance scratch-resistance on all your electronic devices. [1]
- Those better-protected screens are going to get clearer over the next few years, too. One way to get clear, bright and good contrast in the screens is to use carbon nanotubes to shoot electrons at the screen. [2]



Carbon Nanotube. Image Source: from ref. 3

Sources:
[1] Bauer, F., et al. "UV Curing of Nanoparticle Reinforced Acrylates." Nuclear Instruments & Methods in Physics Research Section B-Beam Interactions with Materials and Atoms 265.1 (2007): 87-91.
[2] Rickert, S. “Taking the NanoPulse – Putting The Nano into iPod Nano.” http://www.industryweek.com/ReadArticle.aspx?ArticleID=12240
[3] Materials Research Science Engineering Center. University of Wisconsin-Madison. http://mrsec.wisc.edu/Edetc/nanoquest/carbon/

Flexible Cellphones

Nanoscientists have started working on the material to make futuristic cellphones. With Nokia's nano-enabled concept phone, Morph, your phone will be able to be transformed into any shape you need. This new material could make your cellphone flexible, transparent and self-cleaning.

For More Information Check Out:
Nokia Morph Concept Video

Resource: Nokia Research Center. The Morph Concept. http://research.nokia.com/morph

Helping Save Lives with Nanotechnology

Nanoscience is helping develop the technology to send medical images using cellphones. [1]

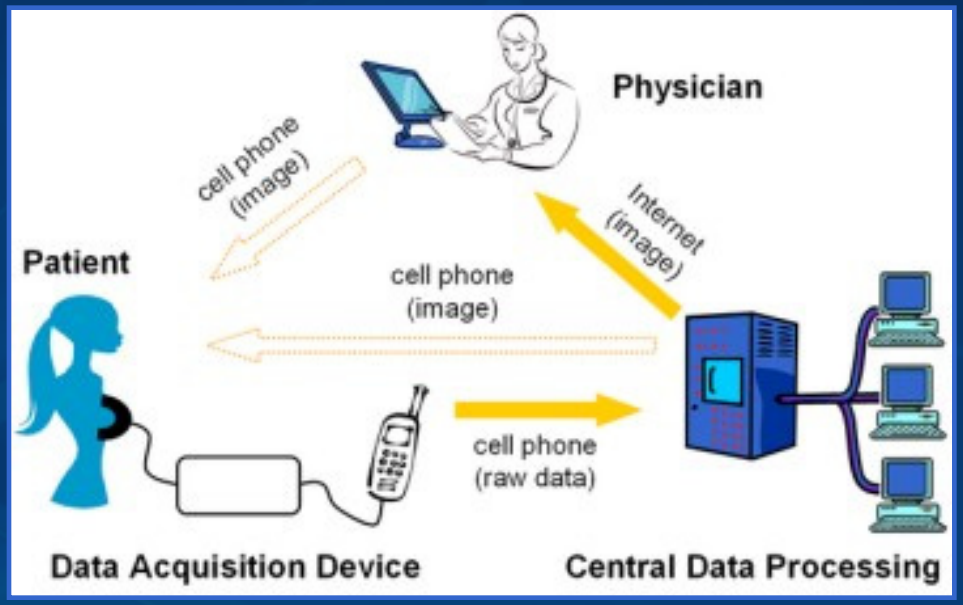


Image Source: from ref. 1

This potentially could bring medical imaging to the 'three-quarters of the world's population which has no access to ultrasounds, X-rays, magnetic resonance images, and other medical imaging technology.' [2]

Resources: [1] Granot Y, Ivorra A, Rubinsky B "A New Concept for Medical Imaging Centered on Cellular Phone Technology." PLoS ONE 3(4): e2075.

[2] The Hebrew University of Jerusalem. "Hebrew University, Berkeley researchers develop method for transmitting medical images via cell phones." http://www.huji.ac.il/cgi-bin/dovrut/dovrut_search_eng.pl?mesge120953840405872560

Ring, Ring

These days, cell phones are music devices, cameras and PDAs all in one. They go everywhere with us – even the theater. But nobody wants to hear a cellphone ring during a movie!

- **Scientists are working on radio-frequency shielding coatings for use in buildings to take care of that problem. [1] Nanomaterials in paint could keep cell phone waves out of the theater. [2] It can shield wireless networks, too, which will make networks more secure. [2]**
- **Next will come shielding coatings on the devices themselves to prevent electromagnetic emissions. No more buzzing when you get close to other electronic devices and may be healthier, too. [1]**

Resources:
[1] Rickert, S. Taking the NanoPulse – Putting The Nano into iPod Nano. http://www.industryweek.com/ReadArticle.aspx?ArticleID=12240
[2] Azim, S. S., et al. "Studies on Graphite Based Conductive Paint Coatings." Progress in Organic Coatings 55.1 (2006): 1-4. Print.

An Earpod Nano?

It might be just around the corner!

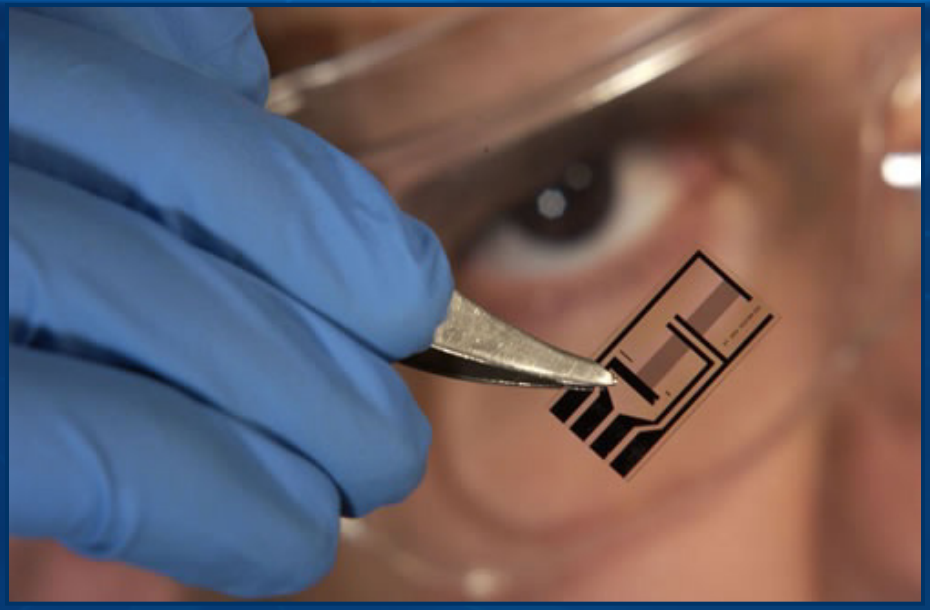


Image Source: from ref. 2

- **Nano-optic components will soon be in your CD and DVD players, too. [1]**
- **And we're on our way to high-speed, conductive ink that can be used for electronics circuitry. These circuits will be 500 nanometers to 2 microns thick and printed on plastic. Your devices will be lighter, thinner, smaller.[2]**

Resources: [1] Lux Research. "Nanotech Venture Capital is Out of Sync with Returns" http://www.impactlab.com/2008/05/08/nanotech-venture-capital-is-out-of-sync-with-returns

[2] Rickert, S. "Taking the NanoPulse – Putting The Nano into iPod Nano." http://www.industryweek.com/ReadArticle.aspx?ArticleID=12240

Nano-Batteries

There's a constant balancing act between increasing battery life and decreasing size and weight. You also need to chose between optimizing for energy bursts, like your camera flash, constant flow, like your laptop, or try to get both, as in a cell phone with a flash camera. [1]

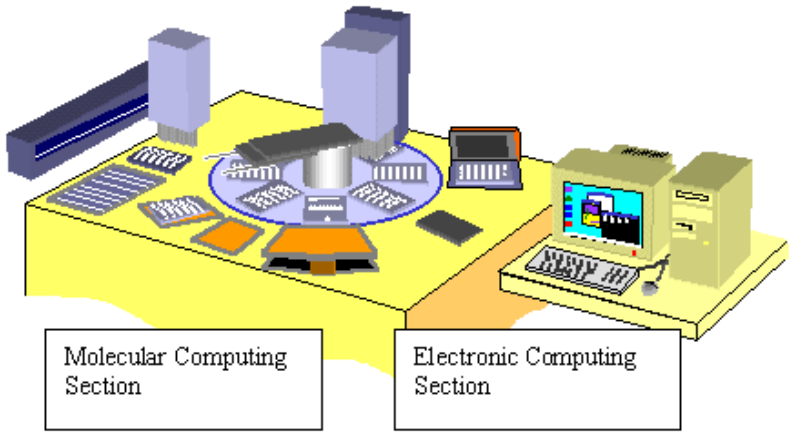
Dell lithium-ion laptop battery
Photo source: Dell

A new type of lithium-ion battery developed for battery-powered power tools may be the nano-key. Companies are claiming battery life as much as 10x greater than presently and they can handle the power bursts. They even recharge in about 10 minutes. [2]

Resources: [1] Rickert, S. "Taking the NanoPulse – Putting The Nano into iPod Nano." http://www.industryweek.com/ReadArticle.aspx?ArticleID=12240

[2] Scrosati, B. Recent Advances in lithium ion battery materials. Electochimica Acta. Vol. 45, Issues 15-16, 3 May 2000, pgs. 2461-2466

DNA Computers



Computations performed with DNA as input/output data; DNA reactions, capture of DNA results and DNA detection all performed automatically.

Information processing program performed; output includes DNA reaction calculations and an analysis of results.

Image Source: from ref. 1

DNA computers are like traditional computers in that they use transistors and store information in bits. [1]

But, DNA computing uses DNA instead of the traditional silicon-based computing technology. These computers are faster, smaller, can store more information and are more secure than traditional computers. [2,3] However, DNA is very fragile and therefore it is unlikely that these computer would take the place of traditional computers.

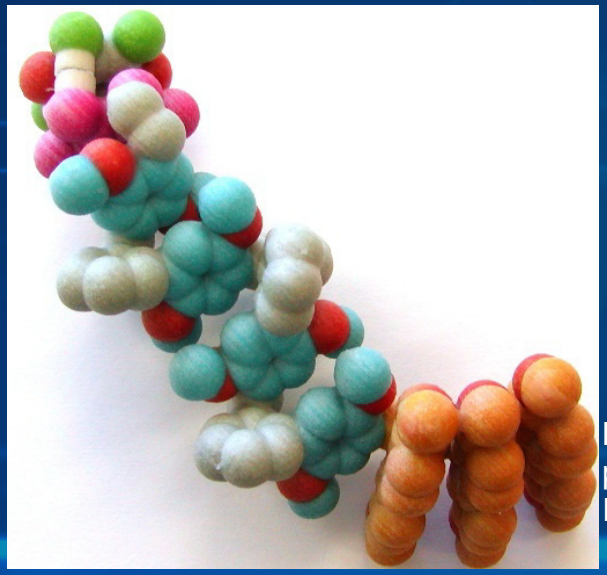
Resources: [1] The Ultimate Renaissance. "Quantum Computer : The revolution" http://theultimaterenaissance.wordpress.com/2008/05/28/quantum-computer-the-revolution/

[2] Xing Wang et al., "A new encryption method based on Rijndael algorithm and DNS computing." Applied Mechanics and Materials, 20-23, 1241. http://www.scientific.net/AMM.20-23.1241

[3] EMARK. "DNA Computers – Generation "z" Borns." http://mallock.blogspot.com/2007/10/dna-computers-generation-z-borns.html

Non-silicon Transistors

Professor Rajendra Rathore at Marquette University is currently studying cofacially-arrayed polybenzenoid nanostructures as a possible transistor that could be eventually used to build computers. They have the advantage of being both very robust and capable of transmitting signals.

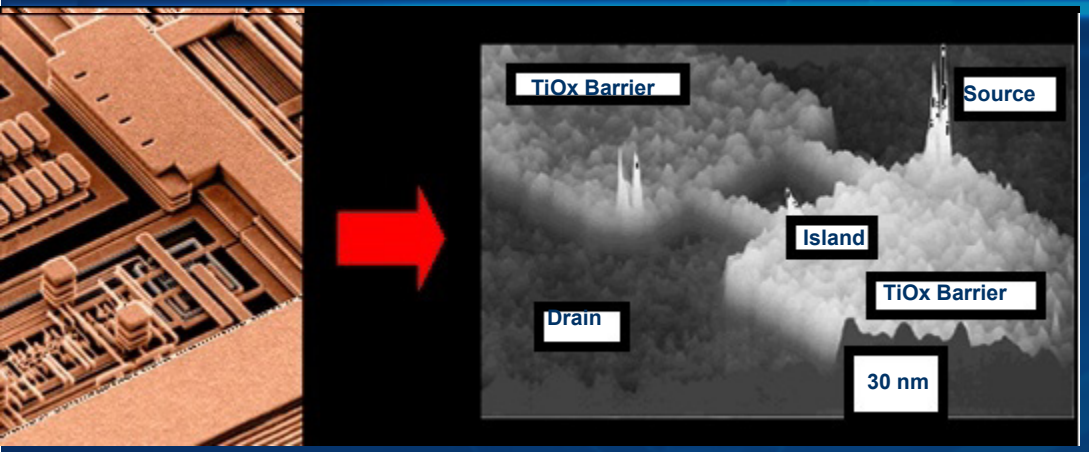


Molecular model of cofacially-arrayed polybenzenoid nano structures
Image Source: Center for BioMolecular Modeling

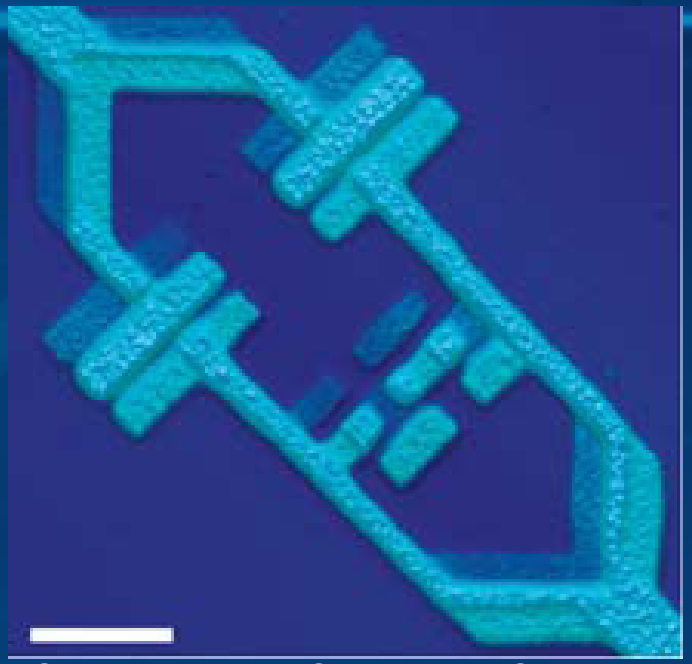
Link to Professor Rathore's Website for more information:
http://www.marquette.edu/chem/RathoreResearchGroup.shtml

Resource: MUHS SMART Team. "DNA Inspired Molecular Wire: Cofacially-Arrayed Polybenzenoid Nano Structures." http://cbm.msoe.edu/includes/pdf/smart2010/MUHS.pdf.

Quantum Computers Use Nanotechnology



Single Electron Transistor. Image Source: from ref. 3



Superconducting Qubit. Image Source: from ref. 2

In quantum computers, information is stored as qubits (quantum bits). [1]

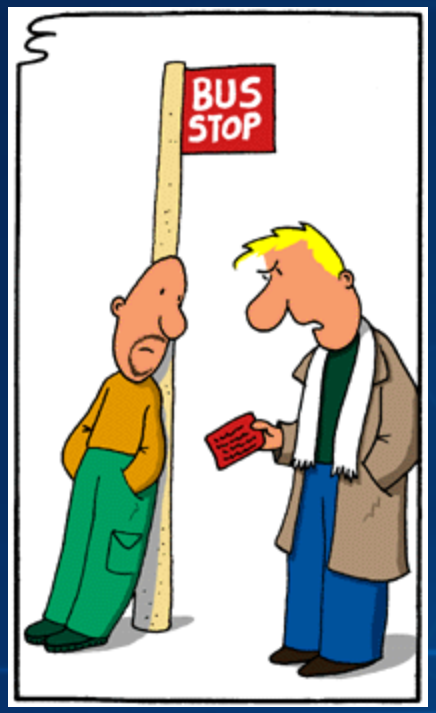
These computers compute differently, too. [2] Quantum computers, using quantum mechanisms, can be devised and built to perform operations with this data. [3]

Learn more about nanotechnology and quantum mechanic challenges at this link.

Resources: [1] Collins, G. "Quantum Bug" Scientific American. http://www.ilorentz.org/~brink/data/1005028.pdf
[2] Benjamin, S.; Ekert, A. "A short introduction to quantum-scale computing" http://www.qubit.org/tutorials/28-quantum-nanocomputing.html
[3] Englund, D. "Linear Optics Quantum Computation." Part of Ph.D. Candidacy Review in Applied Physics. http://cvitae.org/images/stories63/LOQC_englund.pdf

Smart Cards Get Smarter

Image Source: from ref. 2



"At least these Smart Cards gives you something to read whilst you're waiting 2 hours for the next bus." [Image Source from ref. 2]

Nanotechnology is improving smart cards.

A smart card has a microchip in it which makes it 'smart'. It provides not only memory capacity, but computing capability as well and thus the chip is capable of processing data. [1]

Though they're the size of credit cards, they can hold a great deal of information, like your medical history for doctors, pharmacists and even paramedics in an emergency. Unlike magnetic strips on credit cards, this memory won't wear out. [2]

References: [1] Chalasani, S. "Smart Card." University of North Carolina at Charlotte. http://coe.uncc.edu/~jmconrad/ECGR6185-2006-01/notes/smartcards.pdf

[2] Smart Cards. "Smart Cards" http://ewh.ieee.org/r10/bombay/news5/SmartCards.htm

Electronics and Computing Websites

These are websites will provide more information on nanotechnology in electronics and computing. The general website page linked at the bottom of this page is full of nanotechnology sites related to multiple areas including yours.

- National Institute of Standards and Technology nanotechnology webpage http://www.nist.gov/nanotechnology-portal.cfm
- Western Institute of Nanoelectronics (collaborative effort between UC Berkeley, UCLA, UCSB and Stanford) http://www.win-nano.org/
- Articles on nanoelectronics from IEEE Spectrum Magazine Link to search: keyword "nanoelectronics", type "article"
- Article on quality standards in nanoelectronics from IEEE http://spectrum.ieee.org/semiconductors/nanotechnology/its-time-for-a-nanoelectronics-quality-standard
- Nanoscience at the National Science Foundation http://www.nsf.gov/news/overviews/nano/index.jsp

General Nanoscience Website Links

Nano-enabled consumer products

To learn more about nano-enabled consumer products in all areas of research visit the Project on Emerging Nanotechnologies

- Established in April 2005 as a partnership between the Woodrow Wilson International Center for Scholars and the Pew Charitable Trusts
- "The Project is dedicated to helping ensure that as nanotechnologies advance, possible risks are minimized, public and consumer engagement remains strong, and the potential benefits of these new technologies are realized."
- Their website includes news and publications about issues with nanotechnology.
- It also includes inventories of consumer products that are manufacturer-identified as nanotechnology based, and as of the March 10, 2011 update, there are **over 1300 products around the world**.

Resources: **The Project on Emerging Nanotechnologies website:** http://www.nanotechproject.org/

More on the website

If time allows, return to the main website and watch some of the videos that provide “expert testimony” in the area of nanotechnology in electronics and computing.

Click here