One-Day Introduction to Nanoscience

Teacher Materials

Contents

Remaining materials (the introductory student readings, worksheets, worksheet keys and scale diagram) can be found in Lesson 1: Introduction to Nanoscience.

Lesson Plan: One-Day Introduction to Nanoscience

Orientation

This abridged version of the Size Matters unit provides a one-day overview of nanoscience for teachers with very limited time. The goal of this lesson is to spark student's interest in nanoscience, introduce them to common terminology, and get them to start thinking about issues of size and scale. It includes a presentation and visual demonstrations, and recommends use of readings, worksheets, and diagrams from Size Matters Lesson 1.

- The What's the Big Deal about Nanotechnology? PowerPoint introduces size and scale, applications of nanoscience, tools of the nanosciences, and unique properties at the nanoscale.
- The mesogold and/or ferrofluid demonstrations visually illustrate how nanosized particles of a substance exhibit different properties than larger sized particles of the same substance.
- The Introduction to Nanoscience Student Reading and Worksheet (from Lesson 1) explains key concepts such as why nanoscience is different, why it is important, and how we are able to work at the nanoscale.
- The Personal Touch Student Reading and Worksheet (from Lesson 1) focus on applications of nanotechnology (actual and potential) set in the context of a futuristic story. They are designed to spark student's imaginations and get them to start generating questions about nanoscience.
- The Scale Diagram (from Lesson 1) shows, for different size scales, the kinds of objects that are found, the tools needed to "see" them, the forces that are dominant, and the models used to explain phenomena.

If you extend this lesson beyond one day, consider incorporating the following popular activities from Lessons 2 and 3:

- The Number Line/Card Sort Activity (from Lesson 2) has students place objects along a scale and reflect on the size of common objects in relation to each other.
- The Unique Properties Lab Activities (from Lesson 3) demonstrate specific aspects of size-dependent properties without using nanoparticles.

Refer to the "Challenges and Opportunities" chart at the beginning of the unit before starting this lesson. Tell students that although making and using products at the nanoscale is not new, our focus on the nanoscale is new. We can gather data about nanosized materials for the first time because of the availability of new imaging and manipulation tools. You may not know all of the answers to the questions that students may ask. The value in studying nanoscience and nanotechnology is to learn how science understanding evolves and to learn science concepts.

Essential Questions (EQ)

What essential questions will guide this unit and focus teaching and learning?

(Numbers correspond to learning goals overview document)

1. How small is a nanometer, compared with a hair, a blood cell, a virus, or an atom?

2. Why are properties of nanoscale objects sometimes different than those of the same materials at the bulk scale?
4. How do we see and move things that are very small?
6. What are some of the ways that the discovery of a new technology can impact our lives?

Enduring Understandings (EU)

Students will understand:

(Numbers correspond to learning goals overview document)

1. The study of unique phenomena at the nanoscale could change our understanding of matter and lead to new questions and answers in many areas, including health care, the environment, and technology.
2. There are enormous scale differences in our universe, and at different scales, different forces dominate and different models better explain phenomena.
3. Nanosized particles of any given substance exhibit different properties than larger particles of the same substance.
4. New tools for seeing and manipulating increase our ability to investigate and innovate.

Key Knowledge and Skills (KKS)

Students will be able to:

(Numbers correspond to learning goals overview document)

1. Describe, using the conventional language of science, the size of a nanometer. Make size comparisons of nanosized objects with other small objects.
3. Describe an application (or potential application) of nanoscience and its possible effects on society.

Prerequisite Knowledge and Skills

- Familiarity with atoms, molecules and cells.
- Knowledge of basic units of the metric system and prefixes.

Related Standards

- NSES Science and Technology: 12EST2.1, 12EST2.2
- NSES Science as Inquiry: 12ASI2.3
- AAAS Benchmarks: 11D Scale #2

Day	Activity	Time	Materials
Prior to this lesson	*Homework*: (Optional) Reading & Worksheet: The Personal Touch (from Lesson 1)	*30 min*	Copies of The Personal Touch: Student Reading & Worksheet (from Lesson 1)
	Homework: Reading & Worksheet: Introduction to Nanoscience (from Lesson 1)	*40 min*	Copies of Introduction to Nanoscience: Student Reading & Worksheet (from Lesson 1)
Day 1 (50 min)	(Optional) Use The Personal Touch story & worksheet as a basis for class discussion. Identify and discuss some student questions from the worksheet.	8 min	The Personal Touch: Student Reading & Worksheet (from Lesson 1)
	Show and pass around samples of mesogold and/or ferrofluid plus a strong magnet.	2 min	Mesogold Ferrofluid and a strong magnet
	Show the PowerPoint slides: What's the Big Deal about Nanotechnology? Describe and discuss: • The term "nanoscience" and the unit "nanometer" • The tools of nanoscience • Examples of nanotechnology	25 min	What's the Big Deal about Nanotechnology? PowerPoint Slides & Teacher Notes Computer and projector
	Hand out Scale Diagram (from Lesson 1) and explain the important points represented on it.	5 min	Copies of Scale Diagram (from Lesson 1)
	In pairs, have students review answers to the Introduction to NanoScience: Student Worksheet (from Lesson 1)	5 min	
	Return to whole class discussion for questions and comments.	5 min	

One Day Introduction to Nanoscience: Teacher Demonstration Instructions

Overview

Nanotechnology creates and uses structures that have novel properties because of their small size. The following two examples visually illustrate how nanosized particles of a given substance exhibit different properties than larger sized particles of the same substance. Paired with appropriate questions, these visual demonstrations can lead to stimulating discussion with your students.

Mesogold

Nanosized particles of gold—sometimes referred to as "mesogold"— exhibit different properties than bulk gold. For example, mesogold has a different melting point than bulk gold, and the color of mesogold can range from light red to purple depending on the size, shape, and concentration of the gold particles present.

Figure 1. Mesogold colloidal gold from Purest Colloids, Inc. [1]

This difference in color has to do with the nature of interactions among the gold atoms and how they react to outside factors (like light)—interactions that average out in the large bulk material but not in the tiny nanosized particles.

A number of organizations manufacture gold nanoparticles. Mesogold made by Purest Colloids, Inc., contains nanosized particles of gold suspended in water. At 10 parts per million (ppm) the liquid appears clear ruby red in color, illustrating how optical properties (color) of mesogold and bulk gold differ.

The gold nanoparticles in Purest Colloid's mesogold are about 0.65 nanometers in diameter, and each particle consists of approximately 9 gold atoms. An atom of gold is about 0.25 nanometers in diameter, so the gold nanoparticles in Mesogold are only slightly larger than two times the diameter of a single gold atom. These particles stay suspended in deionized water, making it a true colloid. Other companies manufacture slightly larger mesogold particles, typically in the range of 70-90 nm.

Gold nanoparticles are being investigated medical research for use in detecting and killing cancer cells and a variety of other applications. They are also advertised as mineral supplements, but without any accompanying scientific support of health benefits.

More information on mesogold is available on the Purest Colloids website [1].

How to Use It as a Demonstration

Show and pass around one or more samples of the mesogold. You may also want to show and pass around a piece of gold (e.g., a ring or gold foil) for comparison.

Point out to your students how nanosized particles of a given substance (mesogold) exhibit different properties (red color) than larger sized particles of the same substance (bulk gold that looks gold in color).

Questions to stimulate classroom discussion:

1. How do you know the bulk gold (e.g., ring or foil) is really made of gold atoms?

   Possible responses might include that it looks like gold, or because (in the case of a ring) jewelry is often made out of gold or may even have a stamp on it that "verifies" that it is made of gold.

2. What could you do to determine that it is really made of gold atoms?

   You could test its physical properties—such as density, melting point, hardness (through a scratch test)—and compare these with the standard values for gold found in physical data charts.

3. Is it possible that a standard microscope could help determine if it is real gold?

   No. Possible responses might include that a standard light microscope can only has resolution down to 10^{-6} m, but we need to see down to the 10^{-9} m.

4. How do you know the mesogold is really made of gold atoms?

   You could test its physical properties. Scientists use atomic emission spectrography to identify substances like mesogold by their spectral lines.

5. Would the same criteria you used to determine if the bulk gold is really made of gold also work for determining if the mesogold is really made of gold?

   No, the criteria could differ, since nanoparticles exhibit different properties than bulk materials—and if you only have a few nanosized particles, some properties such as melting point and density may not even make sense.

6. What other properties of mesogold might differ from bulk gold?

   Melting point and conductivity are examples of properties that might vary.

Where to Buy It

Mesogold can be ordered from http://www.purestcolloids.com/mesogold_price_list.htm or by calling 609-267-6284 from 9 am to 5 pm Eastern time. Prices range from around $30-$70 per bottle, depending on size (250 or 500 mL) and quantity ordered. One 250 mL bottle should be enough for demonstration purposes.

Ferrofluid

Ferrofluids contain nanoparticles of a magnetic solid, usually magnetite (Fe_3O_4), in a colloidal suspension. The nanoparticles are about 10 nm in diameter. Ferrofluids are interesting because they have the fluid properties of a liquid and the magnetic properties of a solid. For example, a magnet placed just below a dish or cell containing ferrofluid generates an array of spikes in the fluid that correspond to the magnetic lines of force. When the magnet is removed, the spikes disappear.

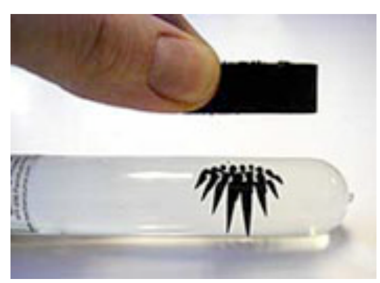


Figure 2. Ferrofluid from Educational Innovations, Inc. [2]

Ferrofluids were discovered by NASA when it was trying to control liquid in space. They have been used in many applications, including computers disk drives, low friction seals and loudspeakers. Medical researchers are even experimenting with using ferrofluids to deliver drugs to specific locations in the body by applying magnetic fields.

More information about ferrofluids is available on the JChemEd web site [3] and the UW-Madison MRSEC web site [4] and [5].

How to Use It as a Demonstration

Show and pass around one or more samples of ferrofluid along with a strong magnet. Let students play with the ferrofluid and magnet and see what they can make it do. You may also want to show and pass around another magnetic material, like a piece of iron, for comparison. Tell your students that since we have been able to make the particles in the ferrofluid so small, we have been able to change the physical state of the material from a solid to a liquid.

Demonstrate that when you bring a magnet close to the liquid, you can see how the particles stream into a star, revealing lines of magnetic force. Point out that this example also illustrates how nanosized particles of a given substance (in this case, a solid called magnetite) exhibit different properties than larger sized particles of the same substance (even though bulk magnetite is a magnetic solid, it does not change visually like the fluid does when you bring a magnet close to it).

Questions to stimulate discussion:

1. What is a liquid?

   A liquid is a fluid that flows and takes the shape of its container. Fluids are divided into liquids and gases. In a liquid, the molecules are close together and have more freedom to move around than a solid but not as much as a gas.

2. When you put the magnet near the ferrofluid, it distorts. What causes this distortion?

   The distortion is caused by the magnetic field of the magnet. The forces exerted by the magnetic field causes the particles of the ferrofluid (which are themselves like “mini-magnets”) to line up in this pattern. Think about how two magnets have some orientations in relation to each other that they like more than others.

3. What does this distortion represent?

   The lines you observe show the direction(s) in which the force field of the magnet acts at each point in space.

4. Why does the solid magnetic material does not distort it’s shape in the same way as the ferrofluid?

   The solid material does not distort because its particles are held more tightly (by attractive van der Waals forces, etc.) and thus must respond to the magnetic force as a group, not as individual particles.

5. If the ferrofluid particles feel magnetic forces of attraction towards each other, why does the fluid not condense into a solid?

The nanoparticles are coated with a stabilizing dispersing agent (surfactant) to prevent particle agglomeration even when a strong magnetic field is brought near the ferrofluid. The surfactant must overcome the attractive van der Waals and magnetic forces between the particles to keep them from clumping together.

Where to Buy It

Sealed display cells of ferrofluid can be ordered from Educational Innovations, Inc., at http://www.teachersource.com (click on "Browse or Search the Catalog", "Electricity! Magnetism! Engines!" and then "Ferrofluids") or call 1-888-912-7474. The Ferrofluid Preform Display Cell (item FF-200) is about $25 and comes with a pair of circle magnets. A Ferrofluid Experiment Booklet is also available (item FF-150) for about $6.

References

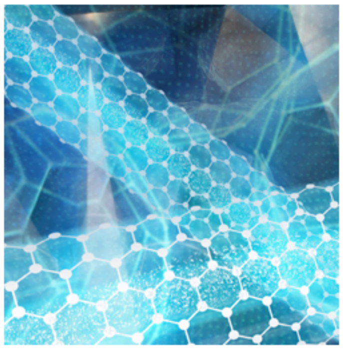
[1] http://www.purestcolloids.com/mesogold.htm

[2] https://www.teachersource.com

[3] http://jchemed.chem.wisc.edu/JCESoft/CCA/CCA2/MAIN/FEFLUID/CD2R1.HTM

[4] http://mrsec.wisc.edu/Edetc/background/ferrofluid/index.html

[5] http://mrsec.wisc.edu/Edetc/IPSE/educators/activities/nanoMed.html



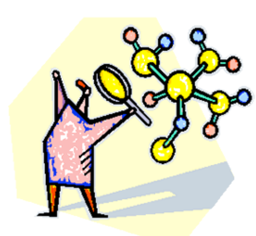
What's the Big Deal about Nanotechnology?

Science at the nanoscale involves a change of perspective!

NanoSense
the basic sense behind nanoscience

What is Nanoscale Science?

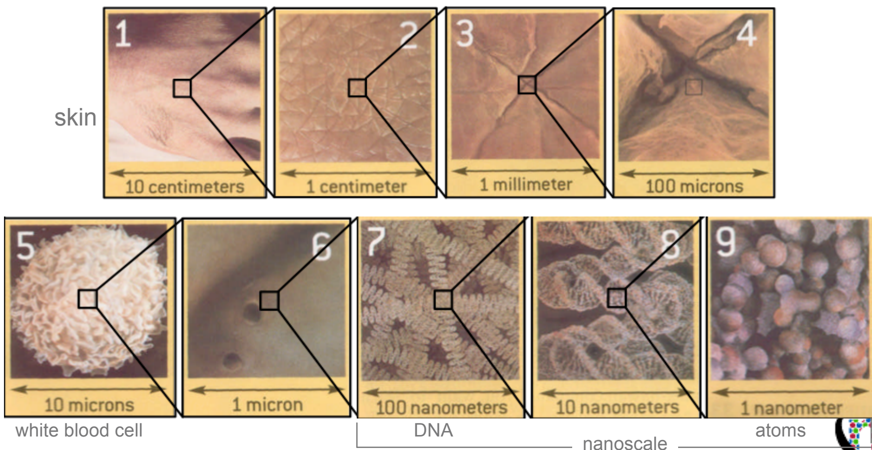
- **The study of objects and phenomena at a very small scale, roughly 1 to 100 nanometers (nm)**
  - 10 hydrogen atoms lined up measure about 1 nm
  - A grain of sand is 1 million nm, or 1 millimeter, wide
- **An emerging, interdisciplinary science involving**
  - Physics
  - Chemistry
  - Biology
  - Engineering
  - Materials Science
  - Computer Science



Source: http://www.cs.utexas.edu/users/s2s/latest/bialt1/src/WhatIsNano/images/molecule.gif

How Big is a Nanometer?

- **Consider a human hand**



Source: http://www.materialsworld.net/nclt/docs/Introduction%20to%20Nano%201-18-05.pdf

Are You a Nanobit Curious?

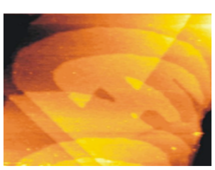
- **What's interesting about the nanoscale?**
  - Nanosized particles exhibit different properties than larger particles of the same substance
- **As we study phenomena at this scale we…**
  - Learn more about the nature of matter
  - Develop new theories
  - Discover new questions and answers in many areas, including health care, energy, and technology
  - Figure out how to make new products and technologies that can improve people's lives

Potential Impacts

How might nanoscale science and engineering improve our lives?

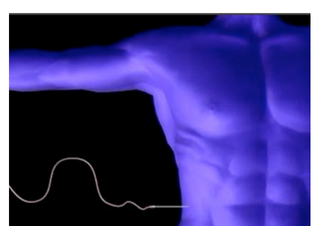
Innovations In Development or Under Investigation

- **Health Care**
  - Chemical and biological sensors, drugs and delivery devices, prosthetics and biosensors
- **Technology**
  - Better data storage and computation
- **Environment**
  - Clean energy, clean air



Thin layers of gold are used in tiny medical devices

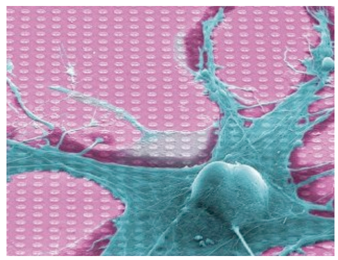
Carbon nanotubes can be used for H fuel storage



Possible entry point for nanomedical device

Health Care: Nerve Tissue Talking to Computers

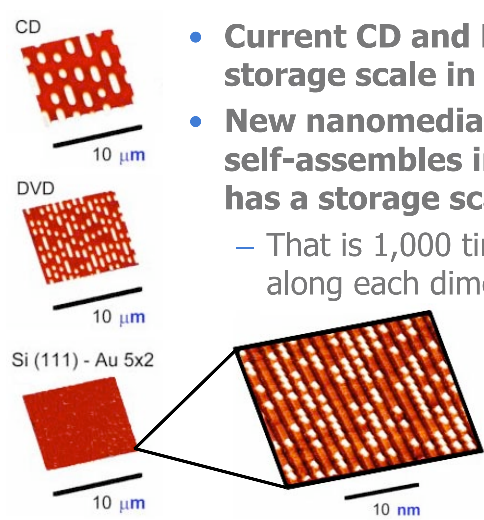
- **Neuro-electronic networks interface nerve cells with semiconductors**
  - Possible applications in brain research, neurocomputation, prosthetics, biosensors



Snail neuron grown on a chip that records the neuron's activity

Source: http://www.biochem.mpg.de/mnphys/publications/05voefro/abstract.html

Technology: A DVD That Could Hold a Million Movies



- **Current CD and DVD media have storage scale in *micrometers***
- **New nanomedia (made when gold self-assembles into strips on silicon) has a storage scale in *nanometers***
  - That is 1,000 times more storage along each dimension (length, width)…

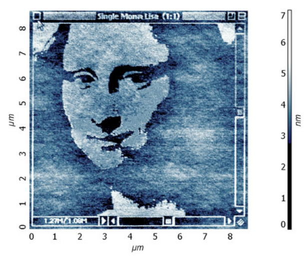
…or 1,000,000 times greater storage density in total!

Source: Images adapted from http://uw.physics.wisc.edu/~himpsel/nano.html

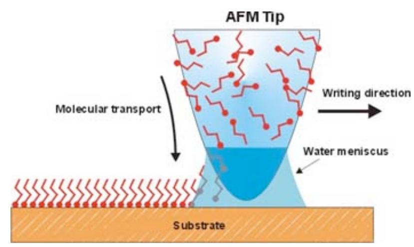
NanoSense 9

Technology: Building Smaller Devices and Chips

- **Nanolithography to create tiny patterns**
  - Lay down “ink” atom by atom



Mona Lisa, 8 microns tall, created by AFM nanolithography



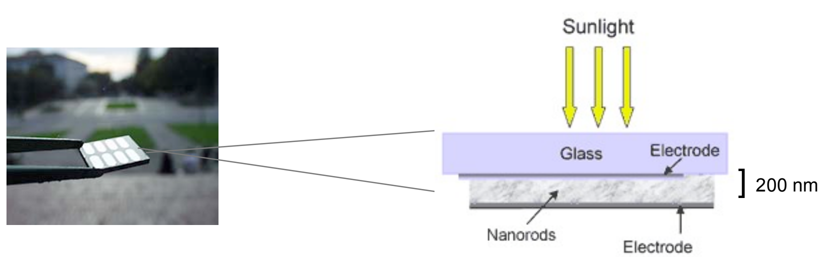
Transporting molecules to a surface by dip-pen nanolithography

Sources: http://www.ntmdt.ru/SPM-Techniques/Principles/Lithographies/AFM_Oxidation_Lithography_mode37.html
http://www.chem.northwestern.edu/~mkngrp/dpn.htm

NanoSense 10

Environment: Nano Solar Cells

- **Nano solar cells mixed in plastic could be painted on buses, roofs, and clothing**
  - Solar becomes a cheap energy alternative!



Nano solar cell: Inorganic nanorods embedded in semiconducting polymer, sandwiched between two electrodes

Source: http://www.berkeley.edu/news/media/releases/2002/03/28_solar.html

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So How Did We Get Here?

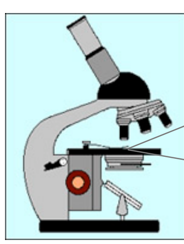
New Tools!

As tools change, what we can see and do changes

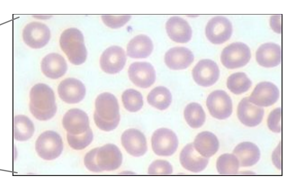
NanoSense 12

Using Light to See

- **The naked eye can see to about 20 microns**
  - A human hair is about 50-100 microns thick
- **Light microscopes let us see to about 1 micron**
  - Bounce **light** off of surfaces to create images



Light microscope
(magnification up to 1000x)

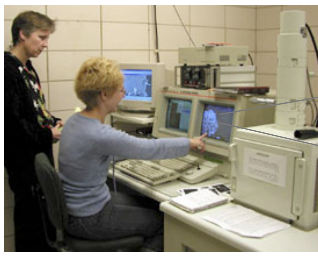


to see red blood cells
(400x)

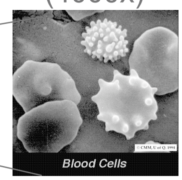
Sources: http://www.cambridge.edu.au/education/PracticeITBook2/Microscope.jpg
http://news.bbc.co.uk/olmedia/760000/images/_764022_red_blood_cells300.jpg

Using Electrons to See

- **Scanning electron microscopes (SEMs), invented in the 1930s, let us see objects as small as 10 nanometers**
  - Bounce **electrons** off of surfaces to create images
  - Higher resolution due to small size of electrons



(4000x)

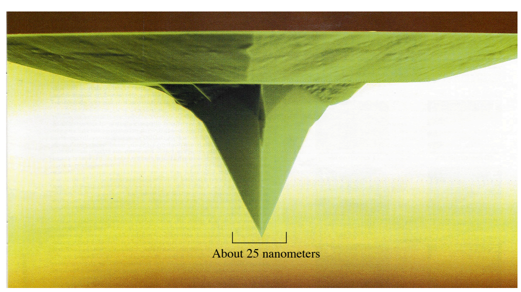


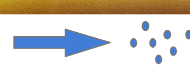
Greater resolution to see things like blood cells in greater detail

Sources: http://w w w .biotech.iastate.edu/facilities/BMF/images/SEMFaye1.jpg
http://cgee.hamline.edu/see/questions/dp_cycles/cycles_bloodcells_bw .jpg

Touching the Surface

- **Scanning probe microscopes, developed in the 1980s, give us a new way to "see" at the nanoscale**
- **We can now image really small things, like atoms, and move them too!**





This is about how big atoms are compared with the tip of the microscope

Source: Scientific American, Sept. 2001

Size-Dependent Properties

So now that we can "see" what's going on…

How do properties change at the nanoscale?

Properties of a Material

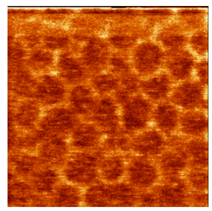
- **A property describes how a material acts under certain conditions**
- **Types of properties**
  - Optical (e.g. color, transparency)
  - Electrical (e.g. conductivity)
  - Physical (e.g. hardness, melting point)
  - Chemical (e.g. reactivity, reaction rates)
- **Properties are usually measured by looking at large (~10^{23}) aggregations of atoms or molecules**

Sources: http://www.bc.pitt.edu/prism/prism-logo.gif
http://www.physics.umd.edu/lecdem/outreach/QOTW/pics/k3-06.gif

Optical Properties Change: Color of Gold

- **Bulk gold appears yellow in color**
- **Nanosized gold appears red in color**
  - The particles are so small that electrons are not free to move about as in bulk gold
  - Because this movement is restricted, the particles react differently with light

"Bulk" gold looks yellow

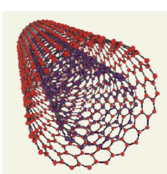


12 nanometer gold clusters of particles look red

Sources: http://www.sharps-jewellers.co.uk/rings/images/bien-hccncsq5.jpg
http://www.foresight.org/Conferences/MNT7/Abstracts/Levi/

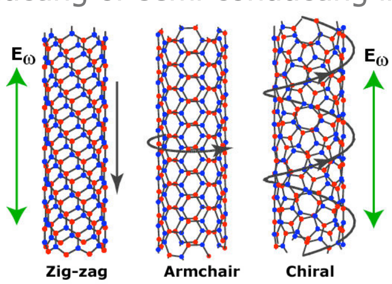
Electrical Properties Change: Conductivity of Nanotubes

- **Nanotubes are long, thin cylinders of carbon**
  - They are 100 times stronger than steel, very flexible, and have unique electrical properties
- **Their electrical properties change with diameter, "twist", and number of walls**
  - They can be either conducting or semi-conducting in their electrical behavior



Multi-walled

Electric current varies by tube structure



Source: http://www.weizmann.ac.il/chemphys/kral/nano2.jpg

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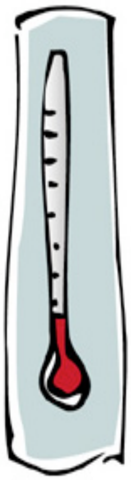
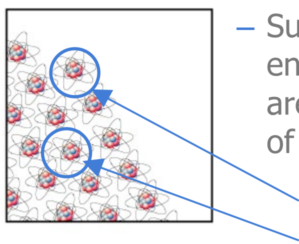
Physical Properties Change: Melting Point of a Substance



- **Melting Point (Microscopic Definition)**
  - Temperature at which the atoms, ions, or molecules in a substance have enough energy to overcome the intermolecular forces that hold the them in a "fixed" position in a solid



  - Surface atoms require *less* energy to move because they are in contact with *fewer* atoms of the substance

Sources: http://puffernet.tripod.com/thermometer.jpg and image adapted from http://serc.carleton.edu/usingdata/nasaimages/index4.html

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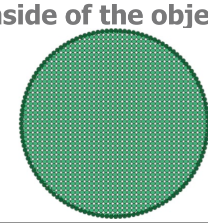
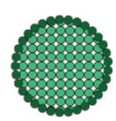
Physical Properties Example: Substance's Melting Point II

	At the macroscale	At the nanoscale
The majority of the atoms are…	**…almost all on the inside of the object** 	**…split between the inside and the surface of the object** 
Changing an object's size…	**…has a very small effect on the percentage of atoms on the surface**	**…has a big effect on the percentage of atoms on the surface**
The melting point…	**…doesn't depend on size**	**… is lower for smaller particles**

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Size Dependant Properties

Why do properties change?

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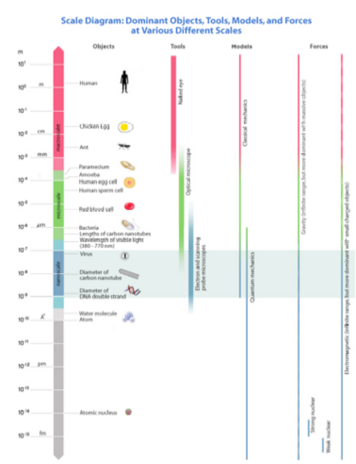
Scale Changes Everything

- **There are enormous scale differences in our universe!**
- **At different scales**
  - Different forces dominate
  - Different models better explain phenomena
- **(See the Scale Diagram handout)**

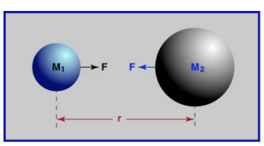


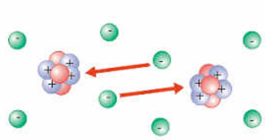
Scale Changes Everything II

- **Four important ways in which nanoscale materials may differ from macroscale materials**
  - Gravitational forces become negligible and electromagnetic forces dominate
  - Quantum mechanics is the model used to describe motion and energy instead of the classical mechanics model
  - Greater surface to volume ratios
  - Random molecular motion becomes more important

Dominance of Electromagnetic Forces

- **Because the mass of nanoscale objects is so small, gravity becomes negligible**





  - Gravitational force is a function of **mass** and distance and is weak between (low-mass) nanosized particles
  - Electromagnetic force is a function of **charge** and distance is not affected by mass, so it can be very strong even when we have nanosized particles
  - The electromagnetic force between two protons is 10^{36} times stronger than the gravitational force!

Sources: http://www.physics.hku.hk/~nature/CD/regular_e/lectures/images/chap04/newtonlaw.jpg
http://www.antonine-education.co.uk/Physics_AS/Module_1/Topic_5/em_force.jpg

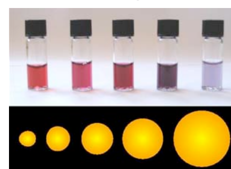
NanoSense 25

Quantum Effects

- **Classical mechanical models that we use to understand matter at the macroscale break down for…**
  - The very small (nanoscale)
  - The very fast (near the speed of light)
- **Quantum mechanics better describes phenomena that classical physics cannot, like…**
  - The colors of nanogold
  - The probability (instead of certainty) of where an electron will be found


Macrogold

Nanogold

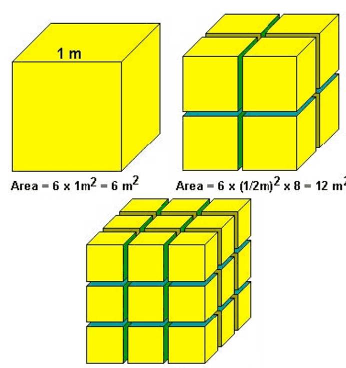


Sources: http://www.phys.ufl.edu/~tschoy/photos/CherryBlossom/CherryBlossom.html
http://www.nbi.dk/~pmhansen/gold_trap.ht; http://www.sharps-jewellers.co.uk/rings/images/bien-hccncsq5.jpg;

NanoSense 26

Surface to Volume Ratio Increases

- **As surface to volume ratio increases**
  - A greater amount of a substance comes in contact with surrounding material
  - This results in better catalysts, since a greater proportion of
    the material is exposed
    for potential reaction



Source: http://www.uwgb.edu/dutchs/GRAPHIC0/GEOMORPH/SurfaceVol0.gif

Random Molecular Motion is Significant

- **Tiny particles (like dust) move about randomly**
  - At the macroscale, we barely see movement, or why it moves
  - At the nanoscale, the particle is moving wildly, batted about by smaller particles

The random path of a dust particle in air

- **Analogy**
  - Imagine a huge (10 meter) balloon being batted about by the crowd in a stadium. From an airplane, you barely see movement or people hitting it; close up you see the balloon moving wildly.

Source: http://www.ap.stmarys.ca/demos/content/thermodynamics/brownian_motion/rand_path.gif

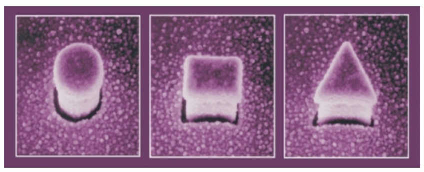
Nanotechnology is a Frontier in Modern-Day Science

What else could we possibly develop?

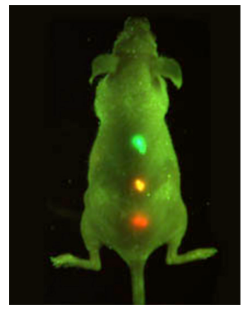
What other things are nanoengineers, researchers and scientists investigating?

Detecting Diseases Earlier

- **Quantum dots glow in UV light**
  - Injected in mice, collect in tumors
  - Could locate as few as 10 to 100 cancer cells



Quantum Dots: Nanometer-sized crystals that contain free electrons and emit photons when submitted to UV light



Early tumor detection, studied in mice

Sources: http://vortex.tn.tudelft.nl/grkouwen/qdotsite.html
http://www.whitaker.org/news/nie2.html

Growing Tissue to Repair Hearts

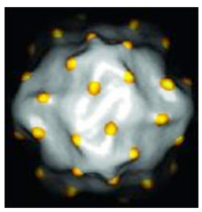
- **Growing cardiac muscle tissue is an area of current research**
  - Grown in the lab now, but the fibers grow in random directions
  - With the help of nanofiber filaments, it grows in an orderly way
- **Could be used to replace worn out or damaged heart tissue**

Cardiac tissue grown with the help of nanofiber filaments

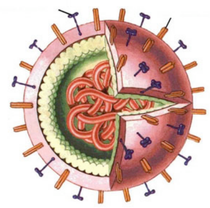
Source: http://www.washington.edu/admin/finmgmt/annrpt/mcdevitt.htm

Preventing Viruses from Infecting Us

- **The proteins on viruses bind to our body cells**
- **Could cover these proteins with nanocoatings**
  - Stop them from recognizing and binding to our cells
  - We would never get the flu!
- **A protein recognition system has been developed**



Gold tethered to the protein shell of a virus

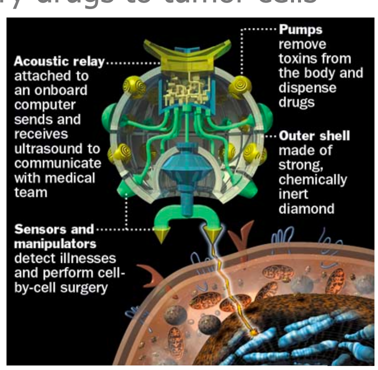


Influenza virus: Note proteins on outside that bind to cells

Sources: http://www.zephyr.dti.ne.jp/~john8tam/main/Library/influenza_site/influenza_virus.jpg
http://pubs.acs.org/cen/topstory/8005/8005notw2.html

Making Repairs to the Body

- **Nanorobots are imaginary, but nanosized delivery systems could…**
  - Break apart kidney stones, clear plaque from blood vessels, ferry drugs to tumor cells



Source: http://www.genomenewsnetwork.org/articles/2004/08/19/nanorobots.php

NanoSense 33

Pause to Consider

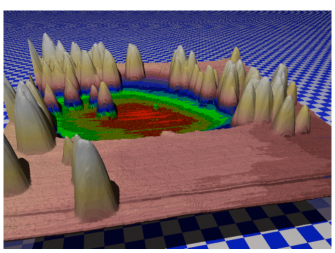
How delicate are nanoscale-sized objects?

How well do we understand the environmental and health impacts of nanosized clusters of particles?

NanoSense 34

Nanodevices Are Sensitive!

- **Radiation particles can cause fatal defects during manufacturing**
  - Development requires very clean environments
  - Only a few, out of many produced, are perfect



Pit created by nuclear radiation (an alpha particle) hitting a mica surface

Sources: http://www.nanopicoftheday.org/2004Pics/February2004/AlphaRecoil.htm
http://www.trnmag.com/Stories/2004/090804/Nano_memory_scheme_handles_defects_Brief_090804.html

NanoSense 35

Potential Risks of Nanotechnology

- **Health issues**
  - Nanoparticles could be inhaled, swallowed, absorbed through skin, or deliberately injected
  - Could they trigger inflammation and weaken the immune system? Could they interfere with regulatory mechanisms of enzymes and proteins?
- **Environmental issues**
  - Nanoparticles could accumulate in soil, water, plants; traditional filters are too big to catch them
- **New risk assessment methods are needed**
  - National and international agencies are beginning to study the risk; results will lead to new regulations

NanoSense 36

Summary: Science at the Nanoscale

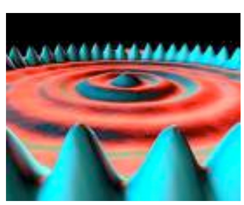
- **An emerging, interdisciplinary science**

Materials Science

Earth Science

Physics

Chemistry



Biology

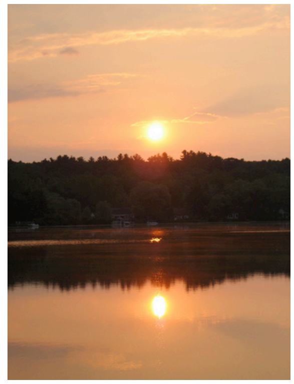
Engineering

Computer Science

Source: http://www.almaden.ibm.com

Nanotechnology: A New Day

- **The nanotechnology revolution will lead to…**
  - **New areas** of research and technology design
  - **Better understanding** of matter and interactions
  - **New ways** to tackle important problems in healthcare, energy, the environment, and technology



Source: http://www.hyperorg.com/blogger/images/sunrise_medium1.jpg

One Day Overview Introduction to Nanoscience Slides: Teacher Notes

Overview

These slides introduce students to what nanoscience is, and capture in a relatively brief overview what is interesting about science at the nanoscale. We want students to see that science is a dynamic, exciting, and evolving undertaking that impacts the world around us through the technological development that accompanies the progress in scientific understanding and tool development.

In contrast to the other lessons in the Size Matters unit that focus primarily (and more deeply) on one aspect of nanoscience, this one-day overview surveys all of the topics addressed by the other Size Matters lessons. Questions such as “How big is a nanometer” and “What are the various types of microscopes used to see small things” are addressed. Properties of materials that can vary at the nanoscale are identified, and some fundamental differences between the nanoscale and bulk scale are highlighted. Finally, examples of currently existing commercial applications, areas of research, and visions for the future are presented. A final slide summarizes key points about nanoscience as an emerging, interdisciplinary science.

Slide 1: What’s the Big Deal about Nanoscience?

Explain to students that you’re going to explain what nanoscience is and how we see small things, and give a few examples of interesting structures and properties of the nanoscale.

Slide 2: What is Nanoscale Science?

Nanoscale science deals with the study of phenomena at a very small scale—10^{-7} m (100 nm) to 10^{-9} m (1 nm)—where properties of matter differ significantly from those at larger scales. This very small scale is difficult for people to visualize. There are several size- and scale-related activities as part of the NanoSense materials that you can incorporate into your curriculum that help students think about the nanoscale.

This slide also highlights that nanoscale science is a multidisciplinary field and draws on areas outside of chemistry, such as biology, physics, engineering and computer science. Because of its multidisciplinary nature, nanoscience may require us to draw on knowledge in potentially unfamiliar academic fields.

Slide 3: How Big is a Nanometer?

This slide gives a “powers of ten” sense of scale. If you are running the slides as a PowerPoint presentation that is projected to the class, you could also pull up one or more powers of ten animations. See http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10 for a nice example that can give students a better sense of small scale.

As you step through the different levels shown in the slide, you can point out that you can see down to about #3 (1000 microns) with the naked eye, and that a typical microscope as used in biology class will get you down to about #5 (10 microns). More advanced microscopes, such as scanning electron microscopes can get you pretty good resolution in the #6 (1 micron) range. Newer technologies (within the last 20 years or so) allow us to "see" in the #7 (100 nanometer) through #9 (1 nanometer) ranges. These are the scanning probe and atomic force microscopes.

Slide 4: Are you a Nanobit Curious?

This slide highlights why we should care about nanoscience: It will change our lives and change our understanding of matter. A group of leading scientists gathered by the National Science Foundation in 1999 said: "The effect of nanotechnology on the health, wealth and standard of living for people in this century could be at least as significant as the *combined* influences of microelectronics, medical imaging, computer-aided engineering and man-made polymers developed in the past century." (Accessed August, 2005, from http://www.techbizfl.com/news_desc.asp?article_id=1792.)

Slide 5: Potential Impacts

The next few slides provide examples of how nanoscale science and engineering might improve our lives.

Slide 6: Innovations In Development or Under Investigation

Point out that tools for manipulating materials are becoming more sophisticated and improving our understanding of how atoms and molecules can be controlled. This will lead to significant improvements in materials, and, in turn, to new products, applications, and markets that could have revolutionary impact on our lives.

This next few slides focus on innovations related to the environment, technology, and healthcare. A few of these products being commercialized now, but most are in research labs or are envisioned for the distant future.

Slide 7: Health Care: Nerve Tissue Talking to Computers

Researchers are studying the electrical interfacing of semiconductors with living cells—in particular, neurons—to build hybrid neuro-electronic networks. Cellular processes are coupled to microelectronic devices through the direct contact of cell membranes and semiconductor chips. For example, electrical interfacing of individual nerve cells and semiconductor microstructures allow nerve tissue to directly communicate their impulses to computer chips. Pictured is a snail neuron grown on a CMOS chip with 128x128 transistors. The electrical activity of the neuron is recorded by the chip, which is fabricated by Infineon Technologies. This research is directed (1) to reveal the structure and dynamics of the cell-semiconductor interface and (2) to build up hybrid neuro-electronic networks. Such research explores the new world at the interface of the electronics in inorganic solids and the ionics in living cells, providing the basis for future applications in medical prosthetics, biosensorics, brain research and neurocomputation.

References:

- Nanopicture of the day from Peter Fromherz: http://www.nanopicoftheday.org/2003Pics/Neuroelectronic%20Interface.htm
- Max Planck research: http://www.biochem.mpg.de/mnphys/

Slide 8: Technology: A DVD That Could Hold a Million Movies

In 1959, Richard Feynman asked if we could ever shrink devices down to the atomic level. He couldn't find any laws of physics against it. He calculated that we could fit all printed information collected over the past several centuries in a 3-dimensional cube smaller than the head of a pin. How far have we come? A 2-dimensional version of Feynman's vision is in research labs. The picture on this slide illustrates the potential of nano-devices for data storage. On the left are images of two familiar data storage media: the CD-ROM and the DVD. On the right is a self-assembled memory on a silicon surface, formed by depositing a small amount of gold on it. It looks like CD media, except that the length scale is in nanometers, not micrometers. So the corresponding storage density is a million times higher! The surface automatically formats itself into atomically-perfect stripes (red) with extra atoms on top (white). These atoms are neatly lined up at well-defined sites along the stripes, but occupy only about half of them. It is theoretically possible to use the presence of an atom to store a 1, and the absence to store a 0. The ultimate goal would be to build a data storage medium that needs only a single atom per bit. The big question is how to write and read such bits efficiently.

References:

- Franz J. Himpsel's web site: http://uw.physics.wisc.edu/~himpsel/nano.html
- R. Bennewitz et al., "Atomic scale memory at a silicon surface" Nanotechnology 13, 499 (2002)

Slide 9: Technology: Building Smaller Devices and Chips

A technique called nanolithography lets us create much smaller devices than current approaches. For example, the Atomic Force Microscope (AFM) nanolithography image of the Mona Lisa was created by a probe oxidation technique. This technique can be used to further miniaturize the electrical components of microchips. Dip pen nanolithography is a 'direct write' technique that uses an AFM to create patterns and to duplicate images. "Ink" is laid down atom by atom on a surface, through a solvent—often water.

References:

- AFM Oxidation nanolithography http://www.ntmdt.ru/SPM-Techniques/Principles/Lithographies/AFM_Oxidation_Lithography_mode37.html
- Dip pen nanolithography: http://www.chem.northwestern.edu/~mkngrp/dpn.htm

Slide 10: Environment: Nano Solar Cells

Enough energy from the sun hits the earth every day to completely meet all energy needs on the planet, if only it could be harnessed. Doing so could wean us off of fossil fuels like oil and provide a clean energy alternative. But currently, solar-power technologies cost as much as 10 times the price of fossil fuel generation. Chemists at U.C. Berkeley are developing nanotechnology to produce a photovoltaic material that can be spread like plastic wrap or paint. These nano solar cells could be integrated with other building materials, and offer the promise of cheap production costs that could finally make solar power a widely used electricity alternative.

Current approaches embed nanorods (bar-shaped semiconducting inorganic crystals) in a thin sheet (200 nanometers deep) of electrically conductive polymer. Thin layers of an electrode sandwich these nanorod-polymer composite sheets. When sunlight hits the sheets, they absorb photons, exciting electrons in the polymer and the nanorods, which make up 90 percent of the composite. The result is a useful current that is carried away by the electrodes. Eventually, nanorod solar cells could be rolled out, ink-jet printed, or even painted onto surfaces, so that even a billboard on a bus could be a solar collector.

References:

- Painting on solar cells: http://www.californiasolarcenter.org/solareclips/2003.01/20030128-6.html
- Cheap, plastic solar cells may be on the horizon: http://www.berkeley.edu/news/media/releases/2002/03/28_solar.html
- New nano solar cells to power portable electronics: http://www.californiasolarcenter.org/solareclips/2002.04/20020416-7.html

Slide 11: So How Did We Get Here?

This slide denotes the beginning of a short discussion of the evolution of imaging tools (i.e. microscopes). One of the big ideas in science is that the creation of tools or instruments that improve our ability to collect data is often accompanied by new science understandings. Science is dynamic. Innovation in scientific instruments is followed by a better understanding of science and is associated with creating innovative technological applications.

Slide 12: Using Light to See

You may want to point out that traditional light microscopes are still very useful in many biology-related applications since things like cells and some of their features can readily be seen with this tool. They are also inexpensive relative to other microscopes and are easy to set up.

Slide 13: Using Electrons to See

Point out that the difference between the standard light microscope and the scanning electron microscope is that electrons, instead of various wavelengths of light, are “bounced” off the surface of the object being viewed, and that electrons allow for a higher resolution because of their small size. You can use the analogy of bouncing bb's on a surface to find out if it is uneven (bb's scattering in all different directions) compared to using beach balls to do the same job.

Slide 14: Touching the Surface

Point out how small the tip of the probe is compared to the size of the atoms in the picture. Point out that this is one of the smallest tips you can possibly make, and that it has to be made from atoms. Also point out that the tip interacts with the surface of the material you want to look at, so the smaller the tip, the better the resolution. But because the tip is made from atoms, it can't be *smaller* than the atoms you are looking at. Tips are made from a variety of materials, such as silicon, tungsten, and even carbon nanotubes.

The different types of scanning probe microscopes are discussed in Lesson 4: Tools of the Nanosciences. For example, in the STM, a metallic tip interacts with a conducting substrate through a *tunneling current* (STM). With the AFM, the van der Waals force between the tip and the surface is the interaction that is traced.

Slide 15: Size-Dependent Properties

The next few slides focus on how nanosized materials exhibit some size-dependent effects that are not observed in bulk materials.

Slide 16: Properties of a Material

It is important to talk with your students about how we know about the properties of materials—how are they measured and on what sized particles are the measurements made? In most cases, measurements are made on macroscale particles, so we tend to have good information on bulk properties of materials but not the properties of nanoscale materials (which may be different).

This slide also points out four types of properties that are often affected by size. This is not an exhaustive list but rather a list of important properties that usually come up when talking about nanoscience.

[Note: This slide summarizes the content in the "What Does it Mean to Talk About the Characteristics and Properties of a Substance?" and "How Do We Know the Characteristics and Properties of Substances?" paragraphs in the Size-Dependant Properties student reading.]

Slide 17: Optical Properties Change: Color of Gold

The gold example illustrates a simple comparison between the nano and bulk properties of a particular material. It is important to point out to your students that we can't say exactly what color a material will always be at a given particle size. This is because there are other factors involved like arrangement of atoms and molecules in the particles and the charge(s) present on particles. However, it is possible to control for these various factors to create desired effects, as in this case the creation of "red" gold using 12 nanometer-sized particles.

[Note: This slide summarizes the content in the "What's Different at the Nanoscale" paragraph in the Size-Dependant Properties student reading.]

Slide 18: Electrical Properties Example: Conductivity of Nanotubes

Electrical properties of materials are based on the movement of electrons and the positively-charged spaces, or "holes," they leave behind. The electronic properties of a nanotube depend on the direction in which the sheet was rolled up. Some nanotubes are metals with high electrical conductivity, while others are semiconductors with relatively large band gaps. Which one it becomes depends on way that it is rolled (also called the "chirality" of the nanotube"). If it's rolled so that its hexagons line up straight along the tube's axis, the nanotube acts as a metal. If it's rolled on the diagonal, so the hexagons spiral along the axis, it acts as a semiconductor. See the "Unique Properties at the Nanoscale: Teacher Reading" for more information.

Slide 19: Physical Properties Change: Melting Point of a Substance

Note that even in a solid, the atoms are not really "fixed" in place but are rather vibrating or rotating around a fixed point. In liquids, the atoms also rotate and move past each other in space (translational motion), although they don't have enough energy to completely overcome the intermolecular forces and move apart as in a gas.

Slide 20: Physical Properties Example: Melting Point of a Substance II

At the nanoscale, a smaller object will have a significantly greater percentage of its atoms on the surface of the object. Since surface atoms need less energy to move (because they are in contact with fewer atoms of the same substance), the total energy needed to overcome the intermolecular forces hold them "fixed" is less and thus the melting point is lower.

Slide 21: Size-Dependant Properties

The next few slides focus on why nanosized materials exhibit size-dependent effects that are not observed in bulk materials.

Slide 22: Scale Changes Everything

Ask your students to refer to the Scale Diagram handout. Use the diagram to point out how there are enormous scale differences in the universe (left part of the diagram), and where different forces dominate and different models better explain phenomena (right part of diagram). Scale differences are also explored in more detail in "Visualizing the Nanoscale: Student Reading" from Lesson 2: Size and Scale.

Slide 23: Scale Changes Everything II

This slide highlights four ways in which nanoscale materials *may* differ from their macroscale counterparts. It is important to emphasize that just because you have a small group of some type of particle, it does not necessarily mean that a whole new set of properties will arise. Whether or not different observable properties arise depends not only on aggregation, but also on the arrangement of the particles, how they are bonded together, etc. This slide sets up the next four slides, where each of the four points (gravity, quantum mechanics, surface to volume ratio, random motion) is described in more detail.

Slide 24: Dominance of Electromagnetic Forces

This slide compares the relative strength between the electromagnetic and gravitational forces. The gravitational force between two electrons is feeble compared to the electromagnetic forces. The reason that you feel the force of gravity, even though it is so weak, is that every atom in the Earth is attracting every one of your atoms and there are a lot of atoms in both you and the Earth. The reason you aren't bounced around by electromagnetic forces is that you have almost the same number of positive charges as negative ones, so you are (essentially) electrically neutral. Gravity is only (as far as we know) attractive. Electromagnetic forces (which include electrical and magnetic forces) can be either attractive or repulsive. Attractive and repulsive forces cancel each other out; they *neutralize* each other. Since gravity has no repulsive force, there's no weakening by neutralization. So even though gravity is much weaker than electrical force, gravitational forces always add to each other; they never cancel out.

Slide 25: Quantum Effects

This slide highlights that, at the nanoscale, we need to use quantum mechanics to describe behavior rather than classical mechanics. The properties reading describe the differences. You can decide how much discussion to have about classical and quantum mechanics with your students. For the purposes of this introductory unit, it is important to let students know that we use a different set of "rules" to describe particles that fall into the nanoscale and smaller range.

Slide 26: Surface to Volume Ratio Increases

This slide highlights the fact that as you decrease particle size, the amount of surface area increases. The three-part graphic on the slide illustrates how, for the same volume, you can increase surface area simply by cutting. Each of the three blocks has the same total volume, but the block that has the most cuts has a far greater amount of surfaces area. This is an important concept since it effects how well a material can interact with other things around it. With your students, you can use following example. Which will cool a glass of water faster: Two ice cubes, or the same two ice cubes (same volume of ice) that have been crushed?

Slide 27: Random Molecular Motion is Significant

This slide highlights the importance of random ("Brownian") motion at small scales. Tiny particles, such as dust, are in a constant state of motion when seen through microscope because they are being batted about by collisions with small molecules. These small molecules are in constant random motion due to their kinetic energy, and they bounce the larger particle around. At the macroscale, random motion is much smaller than the size of the particle, but at the nanoscale this motion is large when compared to the size of the particle.

A nice animation that illustrates this concept is available at http://galileo.phys.virginia.edu/classes/109N/more_stuff/Applets/brownian/brownian.html

Slide 28: Nanotechnology is a Frontier of Modern-Day Science

The next few slides focus on some cutting-edge research and applications that nanoscientists and engineers are working on.

Slide 29: Detecting Diseases Earlier

Quantum dots are small devices that contain a tiny droplet of free electrons, and emit photons when submitted to ultraviolet (UV) light. Quantum dots are considered to have greater flexibility than other fluorescent materials, which makes them suited for use in building nanoscale applications where light is used to process information. Quantum dots can, for example, be made from semiconductor crystals of cadmium selenide encased in a zinc sulfide shell as small as 1 nanometer (one-billionth of a meter). In UV light, each dot radiates a brilliant color.

Because exposure to cadmium could be hazardous, quantum dots have not found their way into clinical use. But they have been used as markers to tag particles of interest in the laboratory. Scientists at Georgia Institute of Technology have developed a new design that protects the body from exposure to the cadmium by sealing quantum dots in a polymer capsule. The surface of each capsule can attach to different molecules. In this case, they attached monoclonal antibodies directed against prostate-specific surface antigen, which is found on prostate cancer cells. The researchers injected these quantum dots into live mice that had human prostate cancers. The dots collected in the tumors in numbers large enough to be visible in ultraviolet light under a microscope. Because the dots are so small, they can be used to locate individual molecules, making them extremely sensitive as detectors. Quantum dots could improve tumor imaging sensitivity tenfold with the ability to locate as few as 10 to 100 cancer cells. Using this technology, we could detect cancer much earlier, which means more successful, easier treatment.

References:

- Quantum dots introduction: http://vortex.tn.tudelft.nl/grkouwen/qdotsite.html
- Lawrence Livermore Labs work in quantum dots: http://www.llnl.gov/str/Lee.html
- Quantum dots light up prostate cancer: http://www.whitaker.org/news/nie2.html

Slide 30: Growing Tissue to Repair Hearts

Cardiac muscle tissue can be grown in the lab, but the fibers grow in random directions. Researchers at the University of Washington are investigating what type of spatial cues they might give heart-muscle cells so that they order themselves into something like the original heart-muscle tissue. Working with one type of heart muscle cell, they have been able to build a two-dimensional structure that resembles native tissue. They use nanofibers to “instruct” muscle cells to orient themselves in a certain way. They have even able to build a tissue-like structure in which cells pulse or ‘beat’ similar to a living heart.

This image on this slide shows cardiac tissue grown with the aid of nanofiber filaments. It displays well-organized growth that is potentially usable to replace worn out or damaged heart tissue. The ultimate goal of building new heart-muscle tissue to repair and restore a damaged human heart is a long way off, but there have been big advances in tissue engineering in recent years.

References:

- University of Washington cardiac muscle work: http://www.washington.edu/admin/finmgmt/annrpt/mcdevitt.htm

Slide 31: Preventing Viruses from Infecting Us

If we could cover the proteins that exist on the influenza virus, we could prevent the virus from recognizing and binding to our body cells. We would never get the flu! A protein recognition system has already been developed. More generally, this work suggests that assembled virus particles can be treated as chemically reactive surfaces that are potentially available to a broad range of organic and inorganic modification.

References

- Virus nanoblocks: http://pubs.acs.org/cen/topstory/8005/8005notw2.html

Slide 32: Making Repairs to the Body

The image on this slide depicts what one nanoscientist from the Foresight Institute imagines might be possible one day in the far future. It shows how a nanorobot could potentially interact with human cells. When people hear of nanotechnology from science fiction, this is often the form that it takes. But we do not know if such a probe is possible. Nanobots like this, if even possible, are probably decades away. What are currently being researched, with hopeful outcomes, are nanosized drug delivery systems that could be used to diagnose disease and fight pathogens.

The fantasy nanobot, for example, could (1) be used to cure skin diseases (embedded in a cream, they could remove dead skin and excess oils, apply missing oils), (2) be added to mouthwash to destroy bacteria and lift plaque or tartar from the teeth to be rinsed away, (3) augment the immune system by finding and disabling unwanted bacteria and viruses, or (4) nibble away at plaque deposits in blood vessels, widening them to prevent heart attacks.

References:

- Nanorobots: medicine of the future: http://www.ewh.ieee.org/r10/bombay/news3/page4.html
- Robots in the body: http://www.genomenewsnetwork.org/articles/2004/08/19/nanorobots.php
- Drexler and Smalley make the case for and against molecular assemblers http://pubs.acs.org/cen/coverstory/8148/8148counterpoint.html

Slide 33: Pause to Consider

The next two slides focus on the delicate nature of nanosized objects, the potential risks of nanotechnology to humans and the environment, and the need study the risks and regulate the development of products that contain nanoparticles.

Slide 34: Nanodevices are Sensitive

Because of their small size, nanodevices are very sensitive and can easily be damaged by, for example, the natural environmental radiation all around us. In the picture for this example, we see a pit caused by an alpha particle hitting the surface of mica. An alpha particle is a high-energy helium nucleus that is the lowest-energy form of nuclear radiation. Alpha particles are also the particles that Rutherford used for the gold foil experiment in which he discovered the arrangement of protons within the atom that is now commonly known as the nucleus. The impact of alpha particles on a solid surface can cause physical damage by causing other atoms in the surface to be moved out of place. These types of defects can be potentially fatal in high-density electronics and nanodevices. To compensate, extremely clean manufacturing environments and very high redundancy—perhaps millions of copies of nanodevices for a given application—are required.

References:

- Fei and Fraundorf on Alpha recoil pits: http://www.nanopicoftheday.org/2004Pics/February2004/AlphaRecoil.htm
- Nano memory scheme handles defects: http://www.trnmag.com/Stories/2004/090804/Nano_memory_scheme_handles_defects_Brief_090804.html

Slide 35: Potential Risks of Nanotechnology

Nanotechnology's potential is encouraging, but the health and safety risks of nanoparticles have not been fully explored. We must weigh the opportunities and risks of nanotechnology in products and applications to human health and the environment. Substances that are harmless in bulk could assume hazardous characteristics because when particles decrease in size, they become more reactive. A growing number of workers are exposed to nanoparticles in the workplace, and there is a danger that the growth of nanotechnology could outpace the development of appropriate safety precautions. Consumers have little knowledge of nanotechnology, but worries are already beginning to spread. For example, environmental groups have petitioned the Food and Drug Administration to pull sunscreens from the market that have nano-size titanium dioxide and zinc oxide particles. As nanotechnology continues to emerge, regulatory agencies must develop standards and guidelines to reduce the health and safety risks of occupational and environmental nanoparticle exposure.

References:

- Risks of nanotechnology: http://en.wikipedia.org/wiki/Nanotechnology
- Overview of nanotechnology: Risks, initiatives, and standardization: http://www.asse.org/nantechArticle.htm

Slides 36: Summary: Science at the Nanoscale

Nanoscience is truly an interdisciplinary science. Progress in nanoscale science and technology results from research involving various combinations of biology, chemistry, physics, materials engineering, earth science, and computer science. Nanoscience also provides a way to revisit the core concepts from these domains and view them through a different lens. Learning about nanoscience can support understanding of the interconnections between the traditional scientific domains and provide compelling, real-world examples of science in action.

Engineering is a discipline rarely discussed in science. Yet, engineering and design are the disciplines that accompany, and sometimes precede, new findings in science. The focus on nanotechnology highlights the intimate nature of the pairing of science and engineering to produce products for society.

Slides 37: Nanotechnology: A New Day

Nanoscience is an emerging science that will change our understanding of matter and help us solve hard problems in many areas, including energy, health care, the environment, and technology. With the power to collect data and to manipulate particles at such a tiny scale, new areas of research and technology design are emerging. Some applications—like stain resistant pants and nanopaint on cars—are here today, but most applications are years or decades away. But nanoscience gives us the potential to understand and manipulate matter more than ever before.