Lesson 3:
Unique Properties at the Nanoscale

Teacher Materials

Contents

Unique Properties at the Nanoscale: Teacher Lesson Plan

Orientation

This lesson is central to understanding the science that occurs at the nanoscale, and contains the most rigorous science content.

- The Unique Properties at the Nanoscale PowerPoint focuses on how and why properties of materials change at the nanoscale.
- The Student Reading on Size-Dependent Properties provides more details on why properties change at the nanoscale. It may be appropriate for students taking college preparatory chemistry.
- The Unique Properties Lab Activities demonstrate specific aspects of size-dependent properties without using nanoparticles. It is appropriate for most students.
- The Unique Properties Quiz tests students understanding of size-dependent properties.

Essential Questions (EQ)

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

(Numbers correspond to learning goals overview document)

2. Why are properties of nanoscale objects sometimes different than those of the same materials at the bulk scale?
5. Why do our scientific models change over time?

Enduring Understandings (EU)

Students will understand: *(Numbers correspond to learning goals overview document)*

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.

Key Knowledge and Skills (KKS)

Students will be able to: *(Numbers correspond to learning goals overview document)*

2. Explain why properties of nanoscale objects sometimes differ from those of the same materials at the bulk scale.

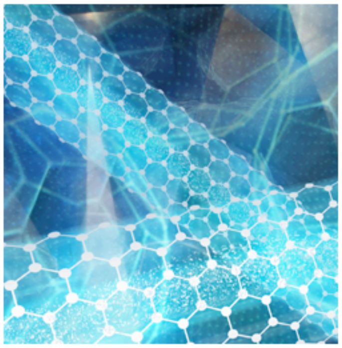
Prerequisite Knowledge and Skills

- Familiarity with properties of matter.
- Some knowledge of atomic structure, Bohr's model of the atoms and the quantum mechanical model of the atom.
- Familiarity with polarity of molecules.

Related Standards

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

Day	Activity	Time	Materials
Prior to this lesson	*Homework*: Reading: Size-Dependent Properties	*45 min*	Photocopies of Size-Dependent Properties: Student Reading
Day 1 (50 min)	Show the PowerPoint slides: Unique Properties at the Nanoscale, using teacher's notes as talking points. Discuss: • Normal properties of a substance. • What properties change from bulk characteristics to nanoscale properties, and how they change* • How the dominance of electromagnetic forces make a difference in properties* • How the quantum mechanical model of the atom, uncertainty of measurement, and tunneling make a difference for nanoscale objects* *Note: Not required by NSES Standards	40 min	PowerPoint slides: Unique Properties at the Nanoscale Computer and Projector
	Prepare for the Unique Properties Station Lab Review student grouping and procedural arrangements	10 min	Photocopies of Student Lab Worksheet
Day 2 (40 min)	Conduct Unique Properties Lab Activity	40 min	Post Student Directions at each station and prepare stations per Teacher Lab Instructions
	Homework: Complete the Student Lab Worksheet	*30 min*	
Day 3 (45 min) (optional)	Discuss student results from the lab activity, and review concepts of unique properties at the nanoscale	30 min	
	Quiz: Unique Properties at the Nanoscale	15 min	Photocopies of Unique Properties at the Nanoscale: Student Quiz Teacher Key for correcting Student Quiz



Unique Properties at the Nanoscale

The science behind nanotechnology

NanoSense
the basic sense behind nanoscience

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

NanoSense 3

Size-Dependent Properties

How do properties change at the nanoscale?

NanoSense 4

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

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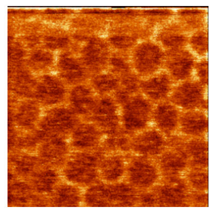
Optical Properties Example: Gold

- **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 particles look red

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

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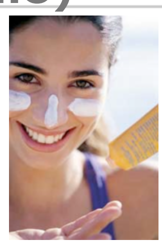
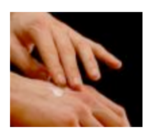
Optical Properties Example: Zinc Oxide (ZnO)

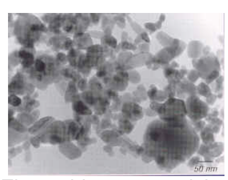
- **Large ZnO particles**
  - Block UV light
  - Scatter visible light
  - Appear white
- **Nanosized ZnO particles**
  - Block UV light
  - So small compared to the wavelength of visible light that they don’t scatter it
  - Appear clear



“Traditional” ZnO sunscreen is white



Nanoscale ZnO sunscreen is clear



Zinc oxide nanoparticles

Sources: http://www.apt powders.com/images/zno/im_zinc_oxide_particles.jpg
http://www.abc.net.au/science/news/stories/s1165709.htm
http://www.4girls.gov/body/sunscreen.jpg

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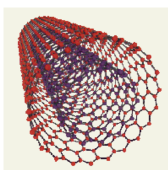
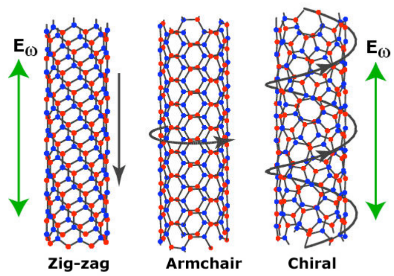
Electrical Properties Example: Conductivity of Nanotubes

- **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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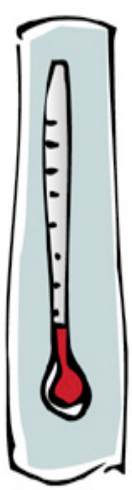
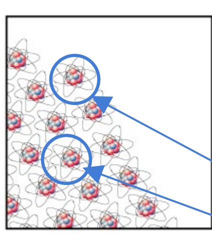
Physical Properties Change: Melting Point of a Substance



- **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

In contact with 3 atoms

In contact with 7 atoms

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

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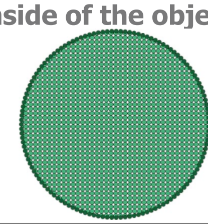
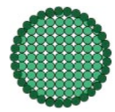
Physical Properties Example: Melting Point of a Substance II

	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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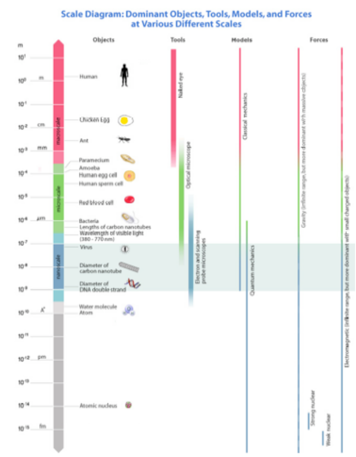
Scale Changes Everything

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



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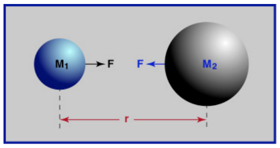
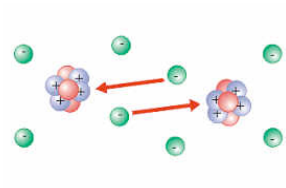
Scale Changes Everything II

- **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 area 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!

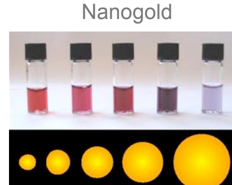
Sources: http://www.physics.hku.hk/~nature/CD/regular_e/lectures/images/chap04/newtonlaw.jpg
http://www.antonine-education.co.uk/Physics_AS/Module_1/Topic_5/em_force.jpg

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;

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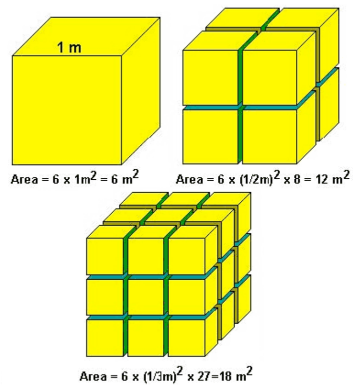
Surface Area to Volume Ratio Increases

- **As surface area 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

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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

- **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

What Does This All Mean?

- **The following factors are key for understanding nanoscale-related properties**
  - Dominance of electromagnetic forces
  - Importance of quantum mechanical models
  - Higher surface area to volume ratio
  - Random (Brownian) motion
- **It is important to understand these four factors when researching new materials and properties**

Unique Properties at the Nanoscale: Teacher Notes

Overview

This series of slides introduces and describes some of the differences in properties between nanoscale and macroscale (bulk) materials and the underlying causes of these differences.

Slide 1: Unique Properties at the Nanoscale

Explain that with the new scientific tools that operate on the nanoscale, we are finding out that many familiar materials act differently and have different characteristics and properties when we have very small (nanoscale) quantities of them. This presentation will discuss these size-dependent properties and why they change at the nanoscale.

Slide 2: Are You a Nanobit Curious?

This slide focuses on the differences in properties between nanoscale and macroscale materials. It is important to emphasize that not all nanoscale materials will exhibit different properties from their macroscale counterparts. The differences in properties depend on many things besides size, including arrangement of atoms and/or molecules in the particles, charge, and shape.

This slide also highlights why we should care about nanoscience: It will change our lives and change our understanding of matter. We are continually learning more and more about the properties of nanoscale particles, including how to manipulate them to suit our needs.

Slide 3: 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 4: Properties of a Material

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 student reading on size-dependent properties. 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.

Slide 5: Optical Properties Example: Gold

The gold example is discussed in the reading and is included here to give a simple comparison between the nano and bulk properties of a particular material. This slide aligns with the “What’s Different at the Nanoscale” paragraph in the properties reading. 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 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.

Slide 6: Optical Properties Example: Zinc Oxide (ZnO)

This slide highlights another properties example that is in the reading. Here a comparison is made between large and nanosized zinc oxide particles—particles typically found in sunscreen. This is a good slide to use to discuss the electromagnetic spectrum, where ultraviolet rays are on the spectrum, and why we are so concerned about them. It can also be used to spark discussion about visible light and how it interacts with matter to allow us to see objects as having different colors and opacities. More detail on this topic is provided in the Nanosense Clear Sunscreen unit.

Slide 7: Electrical Properties Example: Conductivity of Nanotubes

This slide highlights another properties example that is not in the reading. Electrical properties of materials are based on the movement of electrons and the 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 8: Physical Properties Change: Melting Point of a Substance

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

Slide 9: 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 substance), the total energy needed to overcome the intermolecular forces hold them “fixed” is less and thus the melting point is lower.

Slide 10: Size-Dependant Properties

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

Slide 11: 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.

Slide 12: 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 area to volume ratio, random motion) is described in more detail.

Slide 13: 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 14: Quantum Effects

This slide highlights why, at the nanoscale, we need to use quantum mechanics to describe behavior rather than classical mechanics. The properties reading describes 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 15: Surface Area 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 16: 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 17: What Does This All Mean?

This slide summarizes the key ideas in the properties reading: Understanding how electromagnetic forces, quantum models, surface area to volume ratio, and random motion influence properties of nanoscale materials helps us to better understand how to create materials with specific properties.

Unique Properties Lab Activities: Teacher Instructions

Overview

There are three sets of curricular materials for this lab:

1. **Unique Properties Lab Activities: Teacher Instructions**. This document, which includes the purpose, safety precautions, and procedures for each lab station, and a complete list of materials for station. Occasionally, a suggestion is given for optional variations on the labs, under the heading "Teacher Notes."
2. **Unique Properties Lab Activities: Student Instructions**. The set of directions for students is to be printed and posted at each of the appropriate lab stations. They include a statement of purpose, safety precautions, materials needed and procedures for the student to follow.
3. **Unique Properties Lab Activities: Student Worksheet**. Each student should be given this worksheet onto which they will record their observations. The worksheet also includes questions about each lab, designed to stimulate the student to think about how the lab demonstrates concepts fundamental to the mechanisms that make nanotechnology unique.

Each of the following labs is designed to demonstrate a specified aspect of nanotechnology without actually using nanoparticles. The lab is to be set up at multiple stations**.** Each student or group of students will conduct investigations at each station. You may choose to vary the way that students are assigned to lab stations without compromising the learning experience for the students, as long as they have an opportunity to share their thoughts and observations with each other. Note that Lab stations D through H are all on surface area to volume effects.

Post the appropriate Student Instructions at each station for students to follow. There needs to be running tap water and paper towels at each lab station. The instructions for each lab will specify if goggles are needed, as well as any other safety precautions. Each student should have their own lab sheet for recording their data and answering questions.

The lab stations are:

- Serial Dilution Lab
- Ferrofluid Display Cell Lab
- Bubbles Self-Assembly Lab
- Surface Area to Volume Effects… Which Shape Can Dissolve the Fastest?
- More Surface Effects… Faster Explosion?
- More Surface Effects… Is All Water the Same?
- Surface Area to Volume Effects… Burn Baby Burn!
- Surface Area to Volume Effects… Bet I Can Beat'cha!

A complete list of materials can be found on the last page of this set of teacher instructions.

Time Duration

Each lab should take approximately 8 minutes or less. It should take students no more than 50 minutes to complete all of the lab activities. Lab Stations D through G illustrate the concept of surface area to volume ratio effects, so if time is short, you may want to make some of those lab stations optional, use only a subset of these labs, or assign different stations to different groups of students.

Lab Station A:
Serial Dilution Lab

Purpose

The purpose of this lab is to investigate the effects of decreasing the concentration of a solution on the two properties of color and odor. Nanosized materials, (from 1 to 100nm), often appear to have different colors and scents than they do at larger sizes.

Safety Precautions

- Wear goggles while conducting this lab.
- Do not eat or drink anything while in the lab.

Materials

Reagents

A stock solution "assigned" the value of 1.0 Molar. You can use unsweetened, scented Kool-Aid to make the solution. Prepare as directed on the package, and then dilute with twice as much water as the directions indicate. Alternately, you may use 1 drop of food coloring per liter of water, and add an ester of your choice to this mixture. You may have to experiment to ensure that with a 5-part serial dilution, the odor and color change enough from one test tube to another for students to notice.

Materials

- A 1.0 M colored stock solution
- Five test tubes that can hold 10-mL each
- One 25-mL graduated cylinder
- A test tube holder
- Grease marker
- Tap water
- One 1.0-mL graduated pipette, plastic or glass
- A sheet of white paper for background, to help students to judge color

Procedures

Concentration

1. Label each of your test tubes from 1 to 5.
2. Use a pipette to place 10.0 mL of 1.0 Molar of colored solution into test tube #1.
3. Remove 1.0 mL from test tube #1 and inject this into test tube #2. Then add 9.0 mL of water into test tube #2.

4. Remove 1.0 mL from test tube #2 and inject this into test tube #3. Then add 9.0 mL of water into test tube #3.
5. Continue in this fashion until you have completed test tube #5.
6. Note that each subsequent test tube has the concentration of the previous test tube divided by 10.
7. **On your lab sheet,** record the concentration of the solution in each test tube.

Color

1. Hold the white paper behind your test tubes to determine the color change.
2. Use test tube #1 as the strongest color.
3. Continue from test tube #2 to #5 using the gauge below.

1	2	3	4	5
full strength of solution A	→	increasing lighter color	→	no visible color

4. **Record on your lab sheet** the strength of each test tube according to the scale above. At what strength are you no longer able to detect color? Explain why this has happened.

Odor

1. Waft, with your hand, the air over the top of the test tube towards your nose. Sniff. Record the strength of odor according to the scale below on you lab worksheet.
2. Use test tube #1 as the strongest odor.
3. Continue with test tube #2 to #5 in the same manner.

1	2	3	4	5
Odor in test tube #1	→	decreasing strength of odor	→	no odor

4. **Record on your lab sheet** the concentration at which the odor of your solution is no longer detectable. Record other observations and questions as asked on the lab sheet. Explain why you think this happened.

Teacher Notes

If you have a spect-20 spectrophotometer available, you may use this to measure the absorption of each of the five solutions.

Lab Station B:
Ferrofluid Display Cell Lab

Purpose

The purpose of this lab is to design a series of activities that investigate and compare the force of magnetism in ferrofluid (small pieces of iron suspended in fluid) and in a solid piece of iron.

Safety Precautions

- **Do not shake or open the bottle of ferrofluid!**
- Use care when handling glass.

Materials

- One capped bottle of ferrofluid (nanosized iron particles suspended in a solution). A Ferrofluid Preform Display Cell can be obtained for $30 plus tax and shipping from: http://www.teachersource.com/catalog/
  (Search for item “FF-200”)
- A plastic 100mL-graduated cylinder
- A large empty test tube and stopper
- A piece of iron (a slug or rod), about 1-inch in length. This can be purchased from a chemical supply house. You may replace a slug of iron with an iron nail or washer, available from a hardware store. **Note: Most nails are steel rather than iron.**
- Two circle magnets. These magnets come with the ferrofluid display cell. You may add other magnets to provide variety for students.

Procedures

1. Make observations and record your observations of the ferrofluid and the iron object separately.
2. Predict how the magnet will influence the ferrofluid and the iron object.
3. Use the magnets to observe how the force of magnetism influences the ferrofluid and the iron object.
4. Record on your lab sheet your conclusions in the designated place on your lab sheet.

Teacher Notes

You may also check out other ferrofluid products if you are interested. There is an entire kit designed for a variety of experiments using ferrofluid and an experiment booklet you can purchase separately.

Lab Station C:
Bubbles Self-Assembly Lab

Purpose

One of the methods proposed to mass manufacture nanosized objects is to use nature's own natural tendency to self-assemble objects. Fluid or flexible objects will automatically fill the space of the container, taking the most efficient shape. The purpose of this lab is to demonstrate how bubbles self-assemble.

Safety Precautions

- Do not eat or drink anything in lab.
- Use caution when handling glassware.

Materials

- A bubble solution [Bubble Formula: Dawn Ultra or Joy Ultra/ Water (Distilled Water Works Best)/Glycerine or White Karo Syrup (Optional) 1 Part/10 Parts/.25 Parts]
- Small shallow dish
- Toothpicks
- Paper towels
- Straw (coffee stirrers work best)

Procedures

1. Stir the solution with the straw to create bubbles, as needed.
2. Pour about 10.0 mL of bubble solution into the shallow dish.
3. **Caution: Be careful not to spill the solution or to drop the dish!**
4. Draw what you see in your worksheet. This is your "before" diagram.
5. Take the toothpick and pop one of the bubbles. Notice how the arrangement of bubbles changed. Draw what has happened. This is your "after" diagram. Repeat this procedure several times (you do not need to illustrate after the first "before" and "after" observations).

Lab Stations D through G: Surface Area to Volume Effects

Overview

One of the characteristics of nanosized objects is that the surface area to volume ratio is much greater than bulk sized objects. The purpose of lab investigations D through H is to offer a variety of opportunities for students to compare the effects of varying the surface area to volume ratio on the rate of dissolving (Lab D), the rate of bubble formation (Lab E), the time required to boil the same amount of water (Lab F) and the rate of burning (Lab G).

Lab Station D:
Surface Area to Volume Effects…
Which Shape Can Dissolve the Fastest?

Purpose

One of the characteristics of nanosized objects is that the surface area to volume ratio is much greater than bulk sized objects. The purpose of this lab investigation is to compare the effects of varying the surface area to the volume ratio for two samples of the same substance and mass, but different particle size, on the rate of dissolving in water.

Safety Precautions

- Do not eat or drink anything in lab.
- Use caution when handling glassware.
- Wear safety goggles.

Materials

- Two sugar cubes per group
- Granulated sugar, about a cup per class
- A digital balance or scale, with readout to 0.1 gram. A standard laboratory balance can be used instead.
- Two 250-mL Erlenmeyer flasks
- A 100-mL graduated cylinder
- A grease marker
- Tap water, about 50-mL
- A clock or watch with a second hand

Procedures

1. Using a grease marker, label one Erlenmeyer flask #1 and the other #2**.** (These may have already been marked. No need to mark twice.)
2. Set the scale to zero, after placing a square of paper on top of the scale (this is called "**taring**").
3. Measure and record the mass of two cubes of sugar. Put the sugar cubes into flask #1.
4. Measure and record a mass of granulated sugar equal to the mass of the two sugar cubes.
5. Put the granulated sugar into flask #2.
6. Using your graduated cylinder, add 100.0 mL of tap water to each flask.
7. Gently swirl each flask exactly 60 seconds.

8. Record the relative amount of sugar that has dissolved in each flask on your lab sheet.
9. Swirl each flask for another 60 seconds.
10. Record the relative amount of sugar that has dissolved in each flask on your lab sheet. Answer the questions asked about the rates of dissolving.

Teacher Notes

You may vary this lab by:

- Using salt rather than sugar. Salt comes in chunky crystals in rock salt and regular granulated salt.
- Varying the types of sugar to also include superfine and/or powdered sugar.

If you use any additional substances or variations in concentration, you will have to adjust the directions and the materials needed accordingly.

Lab Station E:
More Surface Effects… Faster Explosion?

Purpose

The purpose of the following activities is to give you more experience with examining the effects of changing surface area to volume ratios. **Faster explosion** looks at the effect of different surface area to volume ratios on the speed of reaction.

Safety Precautions

- Do not eat or drink anything in the lab.

Materials

- Two empty film canisters and their lids (clear canisters work better than black)
- One tablet of Alka Seltzer® per group
- One small mortar and pestle
- Clock or watch with a second hand

Procedures

1. Break the Alka Seltzer® tablet in half as exactly as you can.
2. Put one of the halves of the Alka Seltzer® tablet into the mortar and crush it with the pestle until it is finely granulated.
3. Place the uncrushed Alka Seltzer® and the crushed Alka Seltzer® each into a different film canister. Each canister should contain Alka Seltzer® before you proceed to the next step.
4. Simultaneously fill each film canister halfway with tap water. Quickly put their lids on.
5. On your lab sheet, record how much time it takes for each canister to blow its lid off.
6. Rinse the film canisters with water when finished.

Lab Station F:
More Surface Effects… Is All Water the Same?

Purpose

The purpose of the following activities is to provide students with more experience at examining the effects of changing surface area to volume ratios. This lab investigates different surface areas for the same volume of water on the speed of boiling.

Safety Precautions

- Wear safety goggles while conducting this investigation.
- Be careful when handling glass.
- Use extra caution when trying to move hot glassware. Either handle with tongs or wait until glassware is fully cooled.
- Be certain to turn off heat source when you have completed this investigation.

Materials

- Three very different size beakers or flasks. The goal is to get as different as possible surface area among the beakers.
- Hot plate(s) with enough surface area to accommodate the three beakers/flasks, or 3 Bunsen burners
- One 100 mL graduated cyclinder
- A centimeter ruler long enough to measure the diameter of the widest opening of the set of beakers/flasks
- Tongs designed to use with glassware
- Clock or watch

Procedures

1. Fill in the chart on your lab sheet with the size and type of beaker or flask.
2. Fill each of the beakers with 100.0 mL of tap water.
3. Measure the diameter of each of your beakers and record to the nearest mm. For the Erlenmeyer flask, if you are using one, measure the diameter of the water when it is in the flask.
4. Turn on hotplate(s) or Bunsen burners to an equal flame or setting (if using more than one hotplate) **at the same time.** Record the start time on your lab sheet.
5. Record the time that the water begins to boil in each of the beakers/flasks. Record this time in the appropriate column on your lab sheet in the table provided.
6. Fill out the rest of the lab worksheet for this investigation.

Teacher Notes

Students may think that the temperature at which water boils will vary in each of the containers. To avoid this mistaken assumption, you may want to have the students at this lab station measure the temperature in each of the containers at the beginning of boiling. Students should measure the temperature of the water by putting the temperature in the middle of the mass of water, not on the bottom of the beaker or flask.

Lab Station G :
Surface Area to Volume Effects… Burn Baby Burn!

Purpose

These activities are for the purpose of demonstrating the effects of an increased surface area to volume ratio on the rate of combustion (burning).

Safety Precautions

- **Do not pick up any hot items with your fingers or with paper towels. Let cool first.**
- Wear safety goggles.
- Tie back any long hair.

Materials

- One solid rod of steel, about 2-inches or a steel nail (any size) or steel washer about 11/2 inches. These may be purchased at the hardware store.
- Two sets of tongs
- Two Bunsen burners and starters
- A 2-inch section of steel wool, fine or very fine grade, per group. This can be purchased in a hardware store or ordered online from http://www.briwaxwoodcare.com/stelwool.htm

Procedures

1. Light the two Bunsen burners to the same level of flame.
2. Pick up the steel rod or nail with the tongs and heat in the hottest part of the flame for 2 minutes, then remove from flame and let cool. Record your observations on your lab sheet.
3. Pick up the section of steel wool with the tongs and place in the hottest part of the flame for 2 minutes, then remove from flame and let cool. Record your observations on your lab sheet.
4. Once the objects are cooled, deposit any waste into the trash.
5. Answer questions on your lab sheet.

Lab Station H: Surface Area to Volume Effects… Bet I Can Beat'cha!

Purpose

The purpose of this lab activity is to demonstrate the effect of varying surface area to volume ratios of the same materials on the rate of reaction.

Safety Precautions

- Wear goggles during this lab investigation.
- Don't eat or drink anything at your lab station.
- Deposit chemical waste according to the instructions of your teacher. Do not flush solution into the drain.
- Use caution when handling glassware.

Reagent

- One teaspoon $CuCl_2$•$2H_2O$ crystals, per group

Materials

- One teaspoon
- One glass stirring rod
- Two 100 mL beakers
- Two squares, 2 inches x 2 inches, of aluminum foil
- A pair of tongs
- Paper towels and a solid waste disposal
- A clock or watch with a second hand display

Procedures

1. Fill each of the 100 mL beakers about half full with tap water.
2. Add 1 teaspoon of $CuCl_2$•$2H_2O$ crystals to each of the beakers of tap water and mix well with the stirring rod.
3. Form 1 piece of aluminum foil into a loose ball; leave the other piece as is.
4. Put each of the aluminum foil pieces into their own beaker.
5. On your lab sheet, record the time that it takes for each reaction to be complete.
6. Dispose of solution and waste according to your teacher's instructions.

Teacher Notes

Cu^{2+} is a heavy metal and must be disposed of properly according to local and state regulations.

Materials List for All Lab Stations

Lab Station A: Serial Dilution Lab

- A stock solution "assigned" the value of 1.0 Molar. You can use unsweetened, scented Kool-Aid. Prepare as directed on the package, and then dilute with twice as much water as the directions indicate. Alternately, you may use 1 drop of food coloring per liter of water, and add an ester of your choice to this mixture. You may have to experiment to make certain that with a 5-part serial dilution the odor and color change significantly enough from one test tube to another for students to notice.
- Five test tubes that can hold 10-mL each
- One 25-mL graduated cylinder
- A test tube holder
- Grease marker
- Tap water
- One 1.0-mL graduated pipette, plastic or glass
- A sheet of white paper for background to help students to judge color

Lab Station B: Ferrofluid Display Cell Lab

- A plastic 100mL-graduated cylinder
- A large empty test tube and stopper
- A piece of iron (a slug or rod), about 1-inch in length. This can be purchased from a chemical supply house. You may replace a slug of iron with an iron nail or washer, available from a hardware store. **Note: Most nails are steel rather than iron.**
- Two circle magnets. These magnets come with the ferrofluid display tube. You may add other magnets to provide variety for students.
- One capped bottle of ferrofluid (nanosized iron particles suspended in a solution). A Ferrofluid Preform Display Cell can be obtained for $30 plus tax and shipping from: http://www.teachersource.com/catalog/
  (Search for item "FF-200")

You can also check out other ferrofluid products if you are interested. There is an entire kit designed for a variety of experiments using ferrofluid and an experiment booklet you can purchase separately.

Lab Station C: Bubbles Self-Assembly Lab

- A bubble solution [Bubble Formula: Dawn Ultra or Joy Ultra/ Water (Distilled Water Works Best)/Glycerine or White Karo Syrup (Optional) 1 Part/10 Parts/.25 Parts]
- Small shallow dish

- Toothpicks
- Paper towels
- Straw (coffee stirrers work best)

Note: Lab stations D through H are all on surface area to volume effects.

Lab Station D: Which Shape Can Dissolve the Fastest?

- Two sugar cubes per group
- Granulated sugar, about a cup per class
- A digital balance or scale, with readout to 0.1 gram. A standard laboratory balance can be used instead.
- Two 250-mL Erlenmeyer flasks
- A 100-mL graduated cylinder
- A grease marker
- Tap water, about 50-mL
- A clock or watch with a second hand

Lab Station E: Faster Explosion?

- Two empty film canisters and their lids
- One tablet of Alka Seltzer® per group
- One small mortar and pestle
- Clock or watch with a second hand

Lab Station F: Is All Water the Same?

- Three very different size beakers or flasks. The goal is to get as different as possible surface area among the beakers.
- Hot plate(s) with enough surface area to accommodate the three beakers/flasks, or 3 Bunsen burners
- One 100 mL graduated cyclinder
- A centimeter ruler long enough to measure the diameter of the widest opening of the set of beakers/flasks
- Tongs designed to use with glassware
- Clock or watch

Lab Station G: Burn Baby Burn!

- One solid rod of steel, about 2-inches or a steel nail (any size) or steel washer about 11/2 inches. These may be purchased at the hardware store.
- Two sets of tongs

- Two Bunsen burners and starters
- A 2-inch section of steel wool, fine or very fine grade, per group. This can be purchased in a hardware store or ordered online from http://www.briwaxwoodcare.com/stelwool.htm

Lab Station H: Bet I Can Beat'Cha!

- Copper(II)chloride dihydrate crystals ($CuCl_2 \bullet 2H_2O$). Order from any chemical supply house.
- A plastic teaspoon that can be used for measuring the crystals
- One glass-stirring rod. [If a stirring rod is unavailable, the teaspoon may be used to stir. **Caution:** Once the teaspoon has been used to stir the solution, it cannot be used again for measuring out the crystals.]
- Two 100-mL beakers
- Two squares, 2 inches x 2 inches, of aluminum foil
- A pair of tongs
- Paper towels and a solid waste disposal
- A clock or watch with a second hand display

Unique Properties at the Nanoscale: Teacher Reading

Optical Properties

The optical properties of a material result from the interaction of light with the composition and atomic structure of the material. Color, luster, and fluorescence are examples of well-known optical properties. At the nanoscale, some interesting optical properties emerge. Gold nanoparticles are one interesting example, and zinc oxide is another. These substances exhibit different properties as bulk samples compared to nanosized samples, as shown in Table 1, below.

Table 1. Optical properties of gold and zinc oxide for bulk and nano samples.

Substance	Macro, or Bulk Sample	Nanoparticle Sample
Gold	"Gold" in color	"Red" in color
Zinc Oxide (ZnO)	"White" in color	"Clear" in color

What is happening as you go from macro to nano? What underlying principles governing the color changes between a bulk sample or a nano sample for the above two materials?

First, let's consider zinc oxide. Because zinc oxide absorbs ultraviolet light, it can be used in lotions to protect against sunburn. Traditional zinc oxide sunscreen is white in color—you may have used this yourself or seen it on the noses of life guards and swimmer. "Bulk" ZnO is white in color (e.g. lifeguard nose), but nano ZnO is clear. Why is this? The nano ZnO particles don't scatter visible light and they also absorb UV rays. Larger particles (greater than 10^{-7} meters in diameter) tend to scatter visible light but still absorb UV rays.

In the case of gold, the explanation is a bit more complicated, although the process of making gold nanoparticles is centuries old. Long ago, artisans that made stained glass experimented with adding a wide variety of metals and metal salts to their molten glass in order to get the glass to take on certain colors. They discovered that if they mixed fine particles of gold in, the result was a beautiful ruby color. Now these artisans did not know (or really care) exactly *why* this happened, but it does seem curious that gold, a yellow substance, should "stain" glass red. It was not until very recently that the mechanism behind this effect became fully understood.

When light is shone on a piece of metal, the photons kick the electrons in the metal around a bit. In an ordinary chunk of metal, electrons are free to move more or less randomly throughout the metal's crystal structure. However, if you have a very thin film of metal lying upon an insulator (such as glass), the electrons are confined to that thin region. When the light is shone upon them, rather than being free to be bumped around randomly, the electrons will move in a coherent wave.

These coherent waves of electrons are called "surface plasmons." The size of these waves of electrons depends primarily upon the thickness of the film. If an incoming photon has just the right wavelength, its energy will be completely absorbed by the metal, and turned into a surface plasmon. We call this surface plasmon resonance, meaning the incoming photon resonates with the kind of electron waves the film is apt to produce. Photons that do not resonate with the metal film will be reflected back.

The result is that when you shine white light (which consists of photons of many wavelengths) upon such a metal film, the film selectively absorbs photons at a certain small range of wavelengths. What we see reflected back then is the white light with a particular color "subtracted" from it. For example, if you subtract the red photons from white light, the light that is left will look cyan.

The gold nanoparticle story is basically a case of the larger surface area/volume ratio. If the gold has too much interior volume, the effect wouldn't happen; the surface plasmons only occur at interfaces between conductors and nonconductors, and if there's a bunch of "non-interface" (interior) conductors, the effect basically dissipates. So, since the nanoparticles are pretty much all surface you get the Surface Plasmon Resonance (SPR) effect.

While the stained glass makers only had one technique for creating one particular kind of gold nanoparticles, modern scientists and engineers can create an infinite variety of them. Now that the mechanism is understood, researchers have worked to create nanoparticles that are "tuned" to particular frequencies. They can tune the particle by varying its shape, size, and the thickness of the gold film. A recent application of this technology is in cancer treatment. Doctors can embed gold nanoparticles that are tuned to absorb infrared light in cancer cells. Then, the doctor shines infrared light upon the tissue. As the nanoparticles absorb the infrared light, they heat up. Eventually they heat up enough to destroy the cancerous cells.

Electrical Properties

Electrical properties of materials are based on the movement of electrons and the spaces, or "holes," they leave behind. These properties are based on the chemical and physical structure of the material. It turns out that structures at the nanoscale have been found to have some interesting electrical properties. There is a plethora of research involving electrical conductivity and carbon nanotubes, in particular.

A nanotube can be though of as single or multiple sheets of graphite that have been rolled up into a tube, as shown in Figure 1, below.

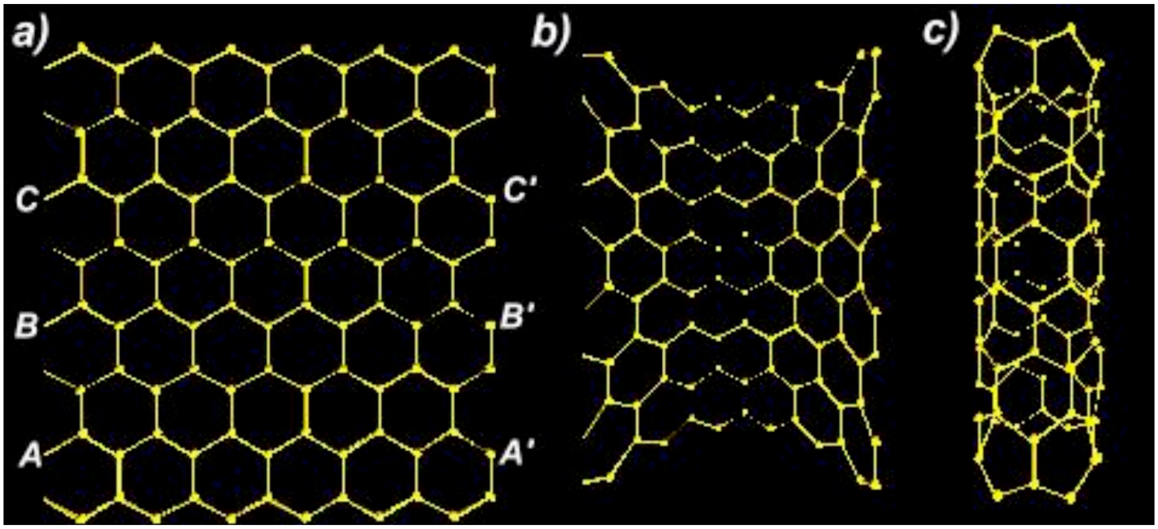

Figure 1. A plane of graphite (left) rolled up (middle) gives you a nanotube (right), matching points A with A', B with B' and so forth [1].

The electronic properties of the resulting 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.

Why is this? As shown above, the wall of a nanotube is similar to graphite in structure. Graphite has one of the four valence electrons delocalized, and therefore can be shared between adjacent carbons. However, it turns out that a single sheet of graphite (also known as graphene) is an electronic hybrid: although not an insulator, it is not a semiconductor or a metal either. Graphene is a "semimetal" or a "zero-gap" semiconductor. When rolled into a carbon nanotube, it becomes either a true metal or a semiconductor, depending on how it is rolled. Shape and geometry make all the difference: diamond, yet another allotrope of carbon that has a 3D tetrahedral structure, is an insulator.

Experiments have been conducted on single walled carbon nanotubes (SWCNT) and multi-walled carbon nanotubes (MWCNT) to discover whether electric conductance within them is *ballistic* or *diffuse*. In a ballistic conductor, all the electrons going into one end come out of the other end without scattering, regardless of how far they have to travel. In a diffuse conductor, some of the electrons are scattered before they get a chance to exit. Experiments suggest that SWCNTs are diffusive, and MWCNTs are ballistic. If adjacent carbon layers in MWCNTs interacted as in graphite, electrons would not be confined to one layer, but research suggests that the current mainly flows through the outermost layer.

One area that is being explored is the possibility of carbon nanotubes being superconductors near room temperature. Superconductors are ballistic conductors that also exhibit a resistance of zero, which means enormous current flow at tiny voltages. At present, we only know of superconductors that work at extremely cold temperatures, below about 130 K (Kelvin; -143°C). Why is superconductivity near room temperature such a big deal? If a material could carry current with no resistance at room temperature, no energy would be lost as heat. This could lead to faster, lower-power electronics, and the ability to carry electricity long distances with 100 per cent efficiency. Although there is no conclusive evidence that nanotubes can be superconductors near room temperature, there are some promising indicators. For example, when the researchers put a magnetic field across a bundle of MWCNT at temperatures up to 400 K (127°C), the bundle generated its own weak, opposing magnetic field. Such a reaction can be a sign of superconductivity. When the MWCNTs cooled off and the magnetic field was turned off, they stayed magnetized. This could be a result of a lingering current within the tubes because there is little resistance to make it fade away—another sign of a superconductor.

Electrical conductivity within carbon nanotubes remains a mystery. There are many theories and models that attempt to predict and describe the electrical conductance of these structures, but they fall short of satisfactory explanations, and in fact, sometimes contradict one another. Research continues in this area.

Carbon nanotubes aren't the only nanoscale structure to exhibit unique electrical properties. For example, if extra electrons are added to buckyballs, they can turn into superconductors. DNA may be used in the future as electrical conductors. Quantum dots have great potential to behave as very small semiconductors, as the electronic structure can be tunable to produce a predictable band gap. Miniature laboratories on a computer chip could employ nanoelectrodes for testing conductance.

Mechanical Properties

Mechanical properties are related to the physical structure of a material. Strength and flexibility are examples of well-known mechanical properties. At the nanoscale, carbon nanotubes have particularly interesting mechanical properties. We will focus on nanotubes here, to illustrate how a nanoscale material can exhibit different properties than their bulk counterparts or other forms of carbon that you are familiar with, like graphite and diamond.

As mentioned in the section on electrical properties, a nanotube is similar to graphite in structure. A nanotube can be thought of as single or multiple sheets of graphite that have been rolled up into a tube. In a sheet of graphite, each carbon atom is strongly bonded to three other atoms, which makes graphite very strong in certain directions. However, adjacent sheets are only weakly bound by van der Waals forces, so layers of graphite can be slide over one another or be peeled apart, as happens when writing with a pencil. The diagram below shows how in graphite, carbon atoms in adjacent layers do not line up and are only weakly held together.

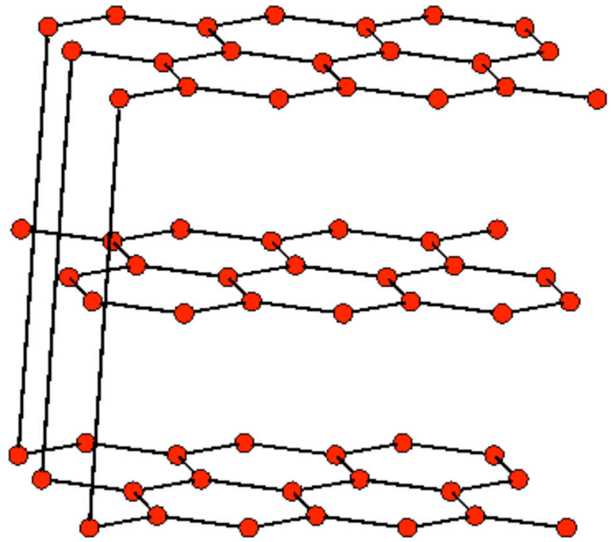

Figure 2. Layered lattice structure of graphite, with widely separated planes that are only weakly held together by weak van der Waals forces [2].

In contrast, it's not easy to peel a carbon layer from a multiwall nanotube. Nanotubes are very strong—one of the strongest materials we know of. They're many times stronger than steel, yet lighter. They are also more resistant to damage; that is, they are highly elastic. Nanotubes can be bent to surprisingly large angles before they start to ripple, buckle, or break. Even severe distortions won't break them (see below).

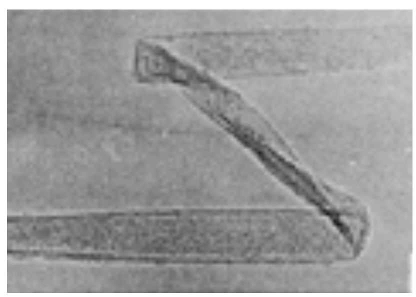

Figure 3. A severely distorted nanotube still doesn't break [3].

Why are nanotubes so strong? We know that each carbon atom within a single sheet of graphite is connected by a strong chemical bond to three neighboring carbon atoms. Why does rolling this strong graphite lattice make an even stronger structure? Because of the resulting geometry: Cylinders are one the strongest known structural shapes because compared to other geometries, stress on the perimeter is more easily distributed throughout the structure. Diamond—a 3D tetrahedral structure where each carbon atom forms 4 bonds—is the strongest material known because of its full covalent bonding. But compared to nanotubes, diamonds have less interesting properties (e.g., they are insulators, they are not elastic, they are denser, and they are very expensive). And some researchers suggest that carbon nanotubes with tiny diameters can approach the strength of diamonds!

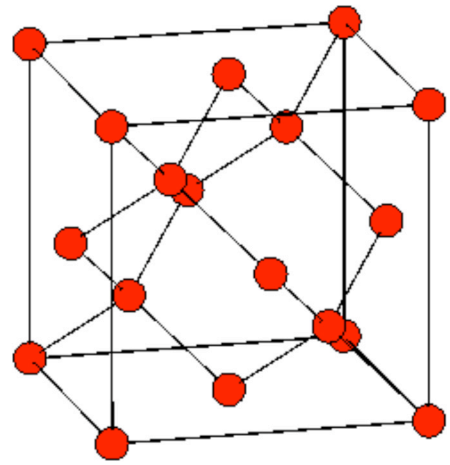

Figure 4. In diamond, each carbon atom forms 4 bonds, tetrahedrally arranged, to other carbon atoms, resulting in a very strongly bonded 3D structure. Very small diameter carbon nanotubes could be as strong as diamond. [4]

Just how strong are nanotubes relative to other materials? Young's Modulus (Y) is one measure of how stiff, or elastic, a material is. The higher this value is, the less it deforms when a force is applied. Another measure, tensile strength, describes the maximum force that can be applied per unit area before the material snaps or breaks. A third interesting measure of a material is the density, which gives you an idea of how light the material is. Table 2, below, shows the Young's Modulus, tensile strength, and density of nanotubes compared to other common materials. (GPa stands for gigapascals.) For example, wood is very light (low density) but weak (low Young's Modulus and low tensile strength), while nanotubes are *many* times stronger than steel (nanotubes have a higher Young's Modulus and much higher tensile strength) and yet much lighter (lower density). Nanotubes also have higher tensile strength even than diamond and a similar (slightly lower) elasticity, and yet they are half as dense.

Table 2. Comparison of mechanical properties of various materials.

Material	Young's Modulus (GPa)	Tensile Strength (GPa)	Density (g/cm3)
Single wall nanotube	~800	>30	1.8
Multi wall nanotube	~800	>30	2.6
Diamond	1140	>20	3.52
Graphite	8	0.2	2.25
Steel	208	0.4	7.8
Wood	16	0.008	0.6

How do researchers measure the stiffness or elasticity of nanotubes? One way is to arrange nantobues like trees on a surface so that they are fixed at the bottom, and then measure the amplitude of the thermal vibrations of the free ends. Another way is to deposit them on a material that has tiny pores (holes) about 200 nm wide. Occasionally a nanotube will span a pore by chance, like a bridge over a valley. They will then apply an AFM tip to the nanotube to see how much load or force it can take before breaking.

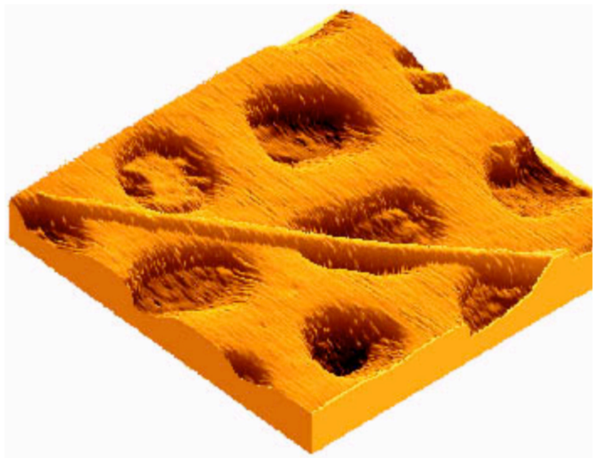

Figure 5. A carbon nanotube on a porous ceramic membrane, ready for mechanical measurements by AFM [5].

What are the implications of such strength? Think of what happened when the materials used for tennis rackets and golf clubs changed from wood to steel, then to composites of carbon—light but strong carbon fibers mixed into another material. The result was lighter, more powerful equipment. Carbon fiber is also used in airplanes to make them stronger and lighter. Carbon nanotubes are 10,000 times thinner than commercial carbon fiber, and much stronger. Adding nanotubes to material used for airplanes or cars, for example, would make them even stronger yet lighter, so less fuel would be needed to move them, reducing operating costs. They could also be used to earthquake-proof homes and bridges. The exceptional strength of nanotubes makes them also attractive as tips for scanning probe microscopes. They might even be used to link Earth to geostationary orbiting space platforms in the form of a space elevator.

In summary, the special properties of carbon nanotubes mean that they could be the ultimate high-strength fiber. The impacts of light and strong structural materials would be enormous.

References and Further Reading

(Accessed August 2005.)

[1] http://schlecht.gmxhome.de/res/tour01/tour13.html

[2] http://www.everyscience.com/Chemistry/Inorganic/Carbon/a.1189.php

[3] http://physicsweb.org/articles/world/11/1/9/1/world%2D11%2D1%2D9%2D6

[4] http://www.everyscience.com/Chemistry/Inorganic/Carbon/a.1189.php

[5] http://ipn2.epfl.ch/CHBU/NTapplications1.htm

Optical properties

- Tiny is beautiful: Translating ‘nano’ into practical: http://www.nytimes.com/2005/02/22/science/22nano.html?pagewanted=1&ei=5070&en=21806c7a33edd6d1&ex=1115265600
- Aussies bask in the summer sun, nanopowders protecting their skin: http://www.smalltimes.com/print_doc.cfm?doc_id=5267
- The surface plasmon spectroscopy is the method of choice in characterizing immobilized molecules in their binding activities: http://www.biochem.mpg.de/oesterhelt/xlab/spfs.html
- Nanoshell-enabled photonics-based imaging and therapy of cancer: http://www.tcrt.org/index.cfm?d=3018&c=4130&p=12032&do=detail

Electrical properties

- Carbon, its allotropes and structures: http://www.everyscience.com/Chemistry/Inorganic/Carbon/a.1189.php
- Multi-wall carbon nanotubes: http://pages.unibas.ch/phys-meso/PublicRelations/PhysicsWorld-MWNT.htm
- Carbon nanotubes, materials for the future: http://www.europhysicsnews.com/full/09/article3/article3.html
- Carbon Nanotubes: http://physicsweb.org/articles/world/11/1/9
- Nanotubes hint at room temperature superconductivity: http://www.newscientist.com/article.ns?id=dn1618
- Berkeley Lab scientists determine electrical properties of carbon-60 molecular layer: http://enews.lbl.gov/Science-Articles/Archive/MSD-C60-molecular-layer.html

Mechanical properties

- Multi-wall carbon nanotubes: http://pages.unibas.ch/phys-meso/PublicRelations/PhysicsWorld-MWNT.htm
- Carbon nanotubes, materials for the future: http://www.europhysicsnews.com/full/09/article3/article3.html
- Mechanical properties table: http://www.applied-nanotech.com/cntproperties.htm#Mechanical%20Properties
- Mechanical properties: http://ipn2.epfl.ch/CHBU/NTapplications1.htm
- Wilson, M. et. al. (2002). Nanotechnology: Basic science and emerging technologies. Boca Raton, FL: CRC Press.
- Carbon nanotubes: http://physicsweb.org/articles/world/11/1/9
- Simulation predicts diamond-strength carbon nanotube fibers: http://composite.about.com/library/PR/2001/blpsu5.htm

Unique Properties at the Nanoscale Quiz: Teacher Key

For questions 1-4, choose which force best matches the statement. *(1 point each)*

a. gravitational force | b. electromagnetic forces

__a__ 1. Describe(s) the attraction of the masses of two particles to each other.

__b__ 2. Dominate(s) for nanosized objects.

__b__ 3. Do/does not vary with mass.

__a__ 4. Stronger for objects with greater mass.

5. Identify a property that doesn't have meaning when you only have a few nanosized particles, and explain why. (*2 points)*

Possible answers include boiling point, melting point, vapor pressure. There aren't enough particles for the property to emerge.

6. Compare the surface-to-volume ratios of a large piece of gold with a nanosized piece of gold. *(1 point)*

The surface-to-volume ratio for the nanosized piece of gold would be much higher than that for a large piece.

7. Explain in your own words why surface-to-volume ratios are important in determining the properties of a substance. You may use a drawing or example to help clarify your explanation. *(3 points)*

When surface-to-volume ratio is low, more particles are in the interior of the substance and subject to similar forces. When it is high, more particles experience forces from the substance as well as from the surrounding material. The effect of this can be seen in a drop of water. The adhesive force of the surface can exceed the attraction of the water molecules to each other and cause the drop to flatten out. Reaction rates also increase as surface-to-volume ration increases, since a greater percentage of the particles are on the surface, which means more particles are immediately available to react. (the collision rate of the reacting molecules increases).

8. Name and explain three properties that are likely to change as when an object is nanosized. You may give examples to help clarify your explanation. *(3 points)*

Answers may include: optical properties (such as color and transparency), electrical properties (such as conductivity), physical properties (such as density and boiling point) and chemical properties (such as reactivities and reaction rates).

9. Explain the concept of electron tunneling and address why this may be a problem for nanosized objects. *(2 points)*

Electrons can jump across small gaps. This could cause defects in nanoscale structures.