Lesson 1: Introduction to Nanoscience

Teacher Materials

Contents

Introduction to Nanoscience: Teacher Lesson Plan

Orientation

This lesson is a first exposure to nanoscience for students. The goal 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.

- The Personal Touch reading, worksheet and class discussion 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 Introduction to Nanoscience reading, PowerPoint slides and worksheet explain key concepts such as why nanoscience is different, why it is important, and how we are able to work at the nanoscale.
- The Scale Diagram 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. This diagram will be used throughout the Size Matters Unit.

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?
5. Why do our scientific models change over time?
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.
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 sized objects.
3. Describe an application (or potential application) of nanoscience and its possible effects on society.

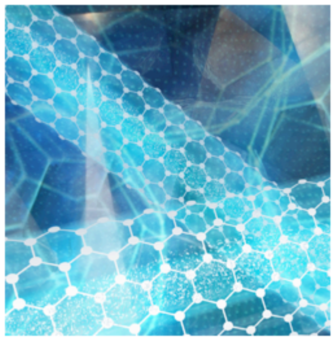
Prerequisite Knowledge and Skills

- Familiarity with atoms, molecules and cells.
- Knowledge of basic units of the metric system and prefixes.
- Ability to manipulate exponential and scientific notation.
- Some knowledge of the light microscope.

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*: The Personal Touch: Reading & Student Worksheet *Homework*: Introduction to Nanoscience: Reading & Student Worksheet	*30 min* *40 min*	Photocopies of readings and worksheets: The Personal Touch Introduction to Nanoscience
Day 1 (50 min)	Use The Personal Touch reading & worksheet as a basis for class discussion. Identify and discuss some student questions from the worksheet.	15 min	
	Show the Introduction to Nanoscience: PowerPoint Slides, using teacher's notes as talking points. Describe and discuss: • The term "nanoscience" and the unit "nanometer" • The tools of nanoscience • Examples of nanotechnology	20 min	Introduction to Nanoscience: PowerPoint Slides Computer and projector
	Hand out Scale Diagram and explain the important points represented on it. Tell students to keep the handout since it will be used throughout the unit.	5 min	Photocopies of Scale Diagram
	In pairs, have students review answers to Introduction to NanoScience: Student Worksheet	5 min	
	Return to whole class discussion for questions and comments.	5 min	



Introduction to Nanoscience

What's happening lately at a very, very small scale

NanoSense
the basic sense behind nanoscience

What is Nanoscale Science?

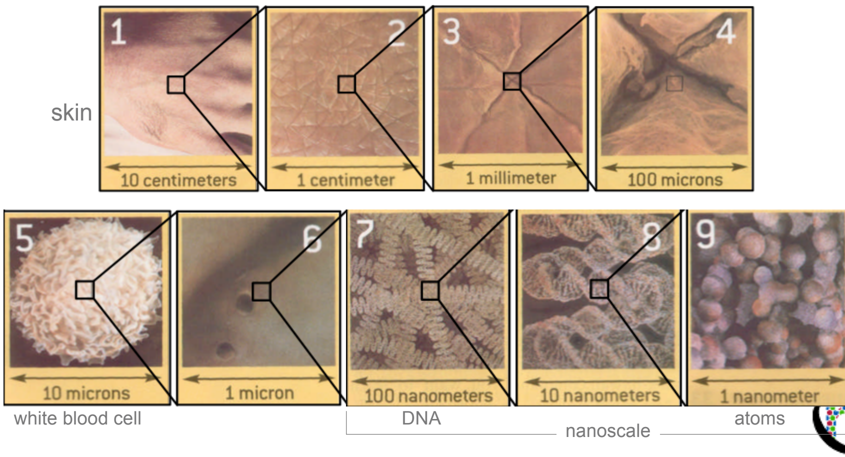
- **The study of objects and phenomena at a very small scale, roughly 1 to 100 nanometers (nm)**
  - 10 hydrogen atoms lined up measure about 1 nm
  - A grain of sand is 1 million nm, or 1 millimeter, wide
- **An emerging, interdisciplinary science involving**
  - Physics
  - Chemistry
  - Biology
 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

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

NanoSense 3

How Big is a Nanometer?

- **Consider a human hand**



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

NanoSense 4

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 5

So How Did We Get Here?

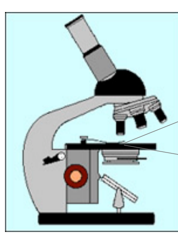
New Tools!

As tools change, what we can see and do changes

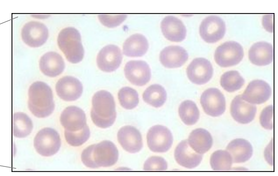
NanoSense 6

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

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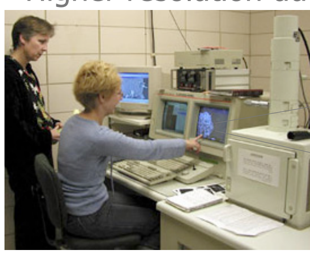
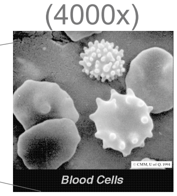
Using Electrons to See

- **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://www.biotech.iastate.edu/facilities/BMF/images/SEMFaye1.jpg
http://cgee.hamline.edu/see/questions/dp_cycles/cycles_bloodcells_bw.jpg

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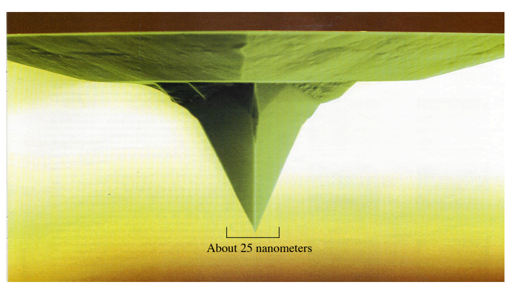
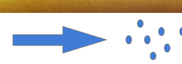
Touching the Surface

- **Scanning probe microscopes, developed in the 1980s, give us a new way to "see" at the nanoscale**
- **We can now see 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

Scanning Probe Microscopes

- **Atomic Force Microscope (AFM)**
  - A tiny tip moves up and down in response to the **electromagnetic forces** between the atoms of the surface and the tip
  - The motion is recorded and used to create an image of the atomic surface
- **Scanning Tunneling Microscope (STM)**
  - A flow of **electrical current** occurs between the tip and the surface
  - The strength of this current is used to create an image of the atomic surface

So What?

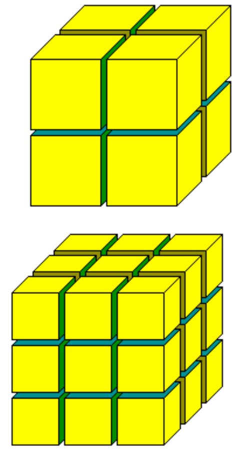
Is nanoscience just seeing and moving really small things?

- **Yes, but it's also a whole lot more. Properties of materials *change* at the nanoscale!**

NanoSense 11

Is Gold Always "Gold"?

- **Cutting down a cube of gold**
  - If you have a cube of pure gold and cut it, what color would the pieces be?
  - Now you cut those pieces. What color will each of the pieces be?
  - If you keep doing this - cutting each block in half - will the pieces of gold always look "gold"?



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

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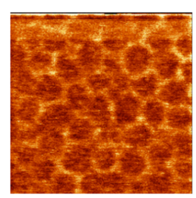
Nanogold

- **Well… strange things happen at the small scale**
  - If you keep cutting until the gold pieces are in the nanoscale range, they don't look gold anymore… They look RED!
  - In fact, depending on size, they can turn red, blue, yellow, and other colors
- **Why?**
  - Different thicknesses of materials reflect and absorb light differently



12 nm gold particles look red

Other sizes are other colors

Source: http://www.nano.uts.edu.au/pics/au_atoms.jpg

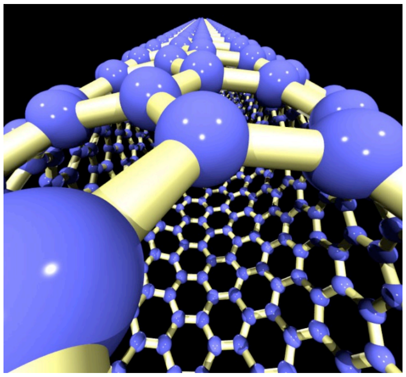
Nanostructures

What kind of nanostructures can we make?

What kind of nanostructures exist in nature?

Carbon Nanotubes

- **Using new techniques, we've created amazing structures like carbon nanotubes**
  - 100 time stronger than steel and very flexible
  - If added to materials like car bumpers, increases strength and flexibility



Model of a carbon nanotube

Source: http://www.library.utoronto.ca/engineering-computer-science/news_bulletin/images/nanotube.jpeg

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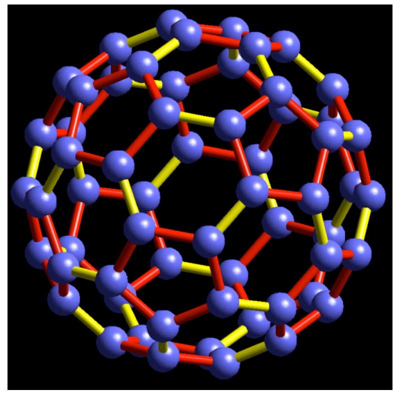
Carbon Buckyballs (C60)

- **Incredible strength due to their bond structure and "soccer ball" shape**
- **Could be useful "shells" for drug delivery**
  - Can penetrate cell walls
  - Are nonreactive (move safely through blood stream)



Model of Buckminsterfullerene

Source: http://digilander.libero.it/geodesic/buckyball-2Layer1.jpg

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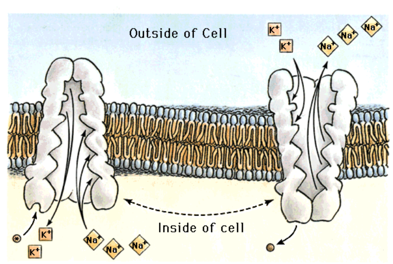
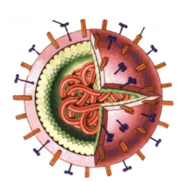
Biological Nanomachines in Nature

- **Life begins at the nanoscale**
  – Ion pumps move potassium ions into and sodium ions out of a cell
  – Ribosomes translate RNA sequences into proteins
  – Viruses infect cells in biological organisms and reproduce in the host cell





Influenza virus

Source: http://faculty.abe.ufl.edu/~chyn/age2062/lect/lect_06/lect_06.htm
http://www.zephyr.dti.ne.jp/~john8tam/main/Library/influenza_site/influenza_virus.jpg

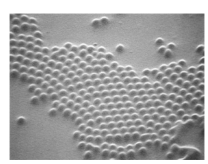
Building Nanostructures

How do you build things that are so small?

Fabrication Methods

- **Atom-by-atom assembly**
  - Like bricklaying, move atoms into place one at a time using tools like the AFM and STM
- **Chisel away atoms**
  - Like a sculptor, chisel out material from a surface until the desired structure emerges
- **Self assembly**
  - Set up an environment so atoms assemble automatically. Nature uses self assembly (e.g., cell membranes)

IBM logo assembled from individual xenon atoms



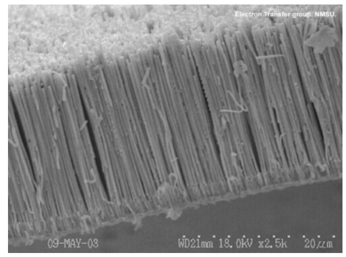
Polystyrene spheres self-assembling

Source: http://www.phys.uri.edu/~sps/STM/stm10.jpg; http://www.nanoptek.com/digitalptm.html

NanoSense

Example: Self Assembly By Crystal Growth

- **Grow nanotubes like trees**
  - Put iron nanopowder crystals on a silicon surface
  - Put in a chamber
  - Add natural gas with carbon (vapor deposition)
  - Carbon reacts with iron and forms a precipitate of carbon that grows up and out



Growing a forest of nanotubes!

- **Because of the large number of structures you can create quickly, self-assembly is the most important fabrication technique**

Source: http://www.chemistry.nmsu.edu/~etrnsfer/nanowires/

Introduction to Nanoscience Slides: Teacher Notes

Overview

This series of slides introduces students to what nanoscience is, how big is a nanometer, various types of microscopes used to see small things, some interesting nanostructures, and interesting properties of these structures.

Slide 1: Introduction to Nanoscience

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

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: 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 6: 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 bacteria can readily be seen with this tool. They are also fairly inexpensive and are easy to set up.

Slide 7: 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 8: 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.

Slide 9: Scanning Probe Microscopes

Point out the difference between the AFM and the STM: the AFM relies on **movement** due to the electromagnetic forces between atoms, and the STM relies on **electrical current** between the tip and the surface. Mention that the AFM was invented to overcomes the STM's basic drawback: it can only be used to sense the nature of materials that conduct electricity, since it relies on the creation of a current between the tip and the surface. The AFM relies on actual contact rather than current flow, so it can be used to probe almost any type of material, including polymers, glass, and biological samples.

Point out that the signals (forces or currents) from these instruments are used to infer an image of the atoms. The tip's fluctuations are recorded and fed into computer models that generate images based on the data. These images give us a rough picture of the atomic landscape.

Slide 10: So What?

The following slides will give examples to help illustrate why we care about seeing and moving things at a very small scale. What makes the science at the nanoscale special is that at such a small scale, different physical laws dominate and properties of materials change.

Slide 11: Is Gold Always Gold?

Help students think about what happens when you keep cutting something down. At what point will you get down to the individual atoms, and at what point does “color” change and go away? Remind them that individual atoms do not have color. The color of a substance is determined by the wavelength of the light that bounces off it, and one atom is too small to reflect light on its own. Only once you have an aggregate (a bunch) of atoms big enough can you begin to discern something approaching “color.” For example, a bunch of salt crystals together look white, but an individual salt crystal is colorless.

Slide 12: Nanogold

Prompt your students to look at their jewelry, etc. and think about color of materials. Use analogies to drive home the concept that different thicknesses of a material can produce different colors. For example, oil on water produces different colors based on how thin the film of oil is. In an oil slick the atoms aren't changing; there are just different thicknesses (numbers of atoms) reflecting different colors. Leaves on a tree look green because the atomic structure on surface of leave reflects back green wavelength and absorbs all others. As leaves die, the atomic structure changes so you get brown reflected back as the chlorophyll breaks down.

For gold, color is based on the crystalline or atomic structure at the nanoscale: light absorbs differently based on the thickness of the crystal. In the Personal Touch story, Sandra's dress changes color because she can change the arrangement of atoms in her dress, which will then reflect different colors.

Slide 13: Nanostructures

The next few slides provide examples of what kind of nanostructures scientists can create and nanostructures that exist in nature.

Slide 14: Carbon Nanotubes

This slide describes a recently-created structure that has some amazing properties. Nanotubes are very light and strong and can be added to various materials to give them added strength without adding much weight. Nanotubes also have interesting conductance (electrical) properties.

Slide 15: Carbon Buckyballs

Buckyballs are another very strong structure based on its interlaced “soccer ball” shape. It has the unique property of being able to carry something inside of it, penetrate a cell wall, and then deliver the package into the cell (not sure how you “open” the buckyball!). It is also non-reactive in general in the body, so your body will not try to attack it and it can travel easy in the bloodstream.

Slide 16: Biological Nanomachines in Nature

There are many natural nanoscale devices that exist in our biological world. Life begins at the nanoscale! For example, inside all cells, molecules and particles of various sizes have to move around. Some molecules can move by diffusion, but ions and other charged particles have to be specifically transported around cells and across membranes. Biology has an enormous number of proteins that self-assemble into nanoscale structures. See the “Introduction to Nanoscience: Student Reading” for more examples.

Slide 17: Building Nanostructures

The next two slides provide examples of how we build things that are so small.

Slide 18: Fabrication Methods

This slide summarizes the three main methods that are used to make nanoscale structures. First, the tips of scanning probe microscopes can form bonds with the atoms of the material they are scanning and *move* the atoms. Using this method with xenon atoms, IBM created the tiniest logo ever in 1990. Alternately, scientists can chisel out material from the surface until the desired structure emerges. This is the process that the computer industry uses to make integrated circuits. Finally, self assembly is the process by which molecular building blocks “assemble” naturally to form useful products. Molecules try to minimize their energy levels by aligning themselves in particular positions. If bonding to an adjacent molecule allows for a lower energy state, then the bonding will occur. We see this happening in many places in nature. For example, the spherical shape of a bubble or the shape of snowflake are a result of molecules minimizing their energy levels. See the “Introduction to Nanoscience: Student Reading” for more information.

Slide 19: Example: Self Assembly By Crystal Growth

One particular type of self-assembly is crystal growth. This technique is used to “grow” nanotubes. In this approach, “seed” crystals are placed on some surface, some other atoms or molecules are introduced, and these particles mimic the pattern of the small seed crystal. For example, one way to make nanotubes is to create an array of iron nanopowder particles on some material like silicon, put this array in a chamber, and add some natural gas with carbon to the chamber. The carbon reacts with the iron and supersaturates it, forming a precipitate of carbon that then grows up and out. In this manner, you can grow nanotubes like trees!

Introduction to Nanoscience Worksheet: Teacher Key

Below is a set of questions to answer during and/or following the introduction to nanoscience slide presentation.

1. What is the range of the "nanoscale"?

Roughly 1 to 100 nanometers (nm) in at least one dimension.

2. What is the smallest size (in meters) that the human eye can see?

The naked eye can see down to about 20 microns (micrometers). One micron is 10^{-6} meters, so ten microns is 10^{-5} meters, and 20 microns is 2×10^{-5} meters. That's 20 millionths of a meter.

3. How much more "power" can a light microscope add to the unaided eye? In other words, what is the smallest resolution that a light microscope can show?

Light microscopes let us see to about 1 micron, or 10^{-6} meters. That's 20 times smaller than the eye can see on its own.

4. Briefly describe how light microscopes and electron microscopes work.

Light microscopes "bounce" visible light of off surfaces to create images. Electron microscopes "bounce" electrons off of surfaces to create images. (Electron microscopes provide higher resolution because electrons are so small, i.e., smaller than a wavelength of visible light.)

5. Name one of the new microscopes that scientists have used to view objects at the nanoscale and explain how that microscope allows you to view objects.

The scanning tunneling microscope (STM) and the atomic force microscope (AFM) are both new scanning probe microscopes (SPM) that can be used to view objects at the nanoscale.

STM: A flow of electrical current occurs between the tip of the microscope probe and the surface of the object. The variation in strength of this current due to the shape of the surface is used to form an image.

AFM: The tip of the microscope probe moves in response to electromagnetic forces between it and the atoms on the surface of the object. As the tip moves up and down, the movement is used to form an image.

6. Give a short explanation of why the nanoscale is "special."

Nanosized particles exhibit different properties than larger particles of the same substance. Studying phenomena at this scale can improve and possibly change our understanding of matter and lead to new questions and answers in many areas.

7. Name one example of a nanoscale structure and describe its interesting properties.

Examples given in the slides: (1) Carbon nanotubes are 100 time stronger than steel, yet very flexible. (2) Carbon buckyballs can pass through cell membranes and be used for drug delivery.