nanosense

NanoSense Curriculum Series | November 2007

Size Matters: Introduction to Nanoscience

NanoSense Curriculum Series

About the NanoSense Project

The goal of the NanoSense project is to help high school students understand science concepts that account for nanoscale phenomena. Working closely with partner teachers and scientists, the NanoSense team has created, classroom tested, and disseminated several units to help students understand underlying principles, applications, and implications of nanoscale science.

License Information

Attribution Information

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Electronic Versions of Materials

Electronic versions of all PowerPoint slides and other materials in this unit are available for download from the NanoSense Web Site at http://nanosense.org

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For Anyone Planning to Teach Nanoscience…
Read This First!

Nanoscience Defined

Nanoscience is the name given to the wide range of interdisciplinary science that is exploring the special phenomena that occur when objects are of a size between 1 and 100 nanometers (10^{-9} m) in at least one dimension. This work is on the cutting edge of scientific research and is expanding the limits of our collective scientific knowledge.

Nanoscience is "Science-in-the-Making"

Introducing students to nanoscience is an exciting opportunity to help them experience science in the making and deepen their understanding of the nature of science. Teaching nanoscience provides opportunities for teachers to:

- Model the process scientists use when confronted with new phenomena
- Address the use of models and concepts as scientific tools for describing and predicting chemical behavior
- Involve students in exploring the nature of knowing: how we know what we know, the process of generating scientific explanations, and its inherent limitations
- Engage and value our student knowledge beyond the area of chemistry, creating interdisciplinary connections

One of the keys to helping students experience science in action as an empowering and energizing experience and not an exercise in frustration is to take what may seem like challenges of teaching nanoscience and turn them into constructive opportunities to model the scientific process. We can also create an active student-teacher learning community to model the important process of working collaboratively in an emerging area of science.

This document outlines some of the challenges you may face as a teacher of nanoscience and describes strategies for turning these challenges into opportunities to help students learn about and experience science in action. The final page is a summary chart for quick reference.

Challenges & Opportunities

1. You will not be able to know all the answers to student (and possibly your own) questions ahead of time …

Nanoscience is new to all of us as science teachers. We can (and definitely should) prepare ahead of time using the resources provided in this curriculum as well as any others we can find on our own. However, it would be an impossible task to expect any of us to become experts in a new area in such a short period of time or to anticipate and prepare for all of the questions that students will ask.

… This provides an opportunity to model the process scientists use when confronted with new phenomena.

Since there is no way for us to become all-knowing experts in this new area, our role is analogous to the "lead explorer" in a team working to understand a very new area of science. This means that it is okay (and necessary) to acknowledge that we don't have all the answers. We can then embrace this situation to help all of our students get involved in generating and researching their own questions. This is a very important part of the scientific process that needs to occur before anyone steps foot in a lab. Each time we teach nanoscience, we will know more, feel more comfortable with the process for investigating what we don't know, and find that there is always more to learn.

One strategy that we can use in the classroom is to create a dedicated space for collecting questions. This can be a space on the board, on butcher paper on the wall, a question "box" or even an online space if we are so inclined. When students have questions, or questions arise during class, we can add them to the list. Students can be invited to choose questions to research and share with the group, we can research some questions ourselves, and the class can even try to contact a nanoscientist to help us address some of the questions. This can help students learn that conducting a literature review to find out what is already known is an important part of the scientific process.

2. Traditional chemistry and physics concepts may not be applicable at the nanoscale level …

One way in which both students and teachers try to deal with phenomena we don't understand is to go back to basic principles and use them to try to figure out what is going on. This is a great strategy as long as we are using principles and concepts that are appropriate for the given situation.

However, an exciting but challenging aspect of nanoscience is that matter acts differently when the particles are nanosized. This means that many of the macro-level chemistry and physics concepts that we are used to using (and upon which our instincts are based) may not apply. For example, students often want to apply principles of classical physics to describe the motion of nanosized objects, but at this level, we know that quantum mechanical descriptions are needed. In other situations it may not even be clear if the macroscale-level explanations are or are not applicable. For example, scientists are still exploring whether the models used to describe friction at the macroscale are useful in predicting behavior at the nanoscale (Luan & Robbins, 2005).

Because students don't have an extensive set of conceptual frameworks to draw from to explain nanophenomena, there is a tendency to rely on the set of concepts and models that they do have. Therefore, there is a potential for students to incorrectly apply macroscale-level understandings at the nanoscale level and thus inadvertently develop misconceptions.

… This provides an opportunity to explicitly address the use of models and concepts as scientific tools for describing and predicting chemical behavior.

Very often, concepts and models use a set of assumptions to simplify their descriptions. Before applying any macroscale-level concept at the nanoscale level, we should have the students identify the assumptions it is based on and the situations that it aims to describe. For example, when students learn that quantum dots fluoresce different colors based on their size, they often want to explain this using their knowledge of atomic emission. However, the standard model of atomic emission is based on the assumption that the atoms are in a gaseous form and thus so far apart that we can think about their energy levels independently. Since quantum dots are very small crystalline solids, we have to use different models that think about the energy levels of the atoms together as a group.

By helping students to examine the assumptions a model makes and the conditions under which it can be applied, we not only help students avoid incorrect application of concepts, but also guide them to become aware of the advantages and limitations of conceptual models in science. In addition, as we encounter new concepts at the nanoscale level, we can model the way in which scientists are constantly confronted with new data and need to adjust (or discard) their previous understanding to accommodate the new information. Scientists are lifelong learners and guiding students as they experience this process can help them see that it is an integral and necessary part of doing science.

3. Some questions may go beyond the boundary of our current understanding as a scientific community…

Traditional chemistry curricula primarily deal with phenomena that we have studied for many years and are relatively well understood by the scientific community. Even when a student has a particularly deep or difficult question, if we dig enough we can usually find ways to explain an answer using existing concepts. This is not so with nanoscience! Many questions involving nanoscience do not yet have commonly agreed upon answers because scientists are still in the process of developing conceptual systems and theories to explain these phenomena. For example, we have not yet reached a consensus on the level of health risk associated with applying powders of nanoparticles to human skin or using nanotubes as carriers to deliver drugs to different parts of the human body.

… This provides an opportunity to involve students in exploring the nature of knowing: how we know what we know, the process of generating scientific explanations, and its inherent limitations.

While this may make students uncomfortable, not knowing a scientific answer to why something happens or how something works is a great opportunity to help them see science as a living and evolving field. Highlighting the uncertainties of scientific information can also be a great opportunity to engage students in a discussion of how scientific knowledge is generated. The ensuing discussion can be a chance to talk about science in action and the limitations on scientific research. Some examples that we can use to begin this discussion are: Why do we not fully understand this phenomenon? What (if any) tools limit our ability to investigate it? Is the phenomenon currently under study? Why or why not? Do different scientists have different explanations for the same phenomena? If so, how do they compare?

4. Nanoscience is a multidisciplinary field and draws on areas outside of chemistry, such as biology, physics, and computer science…

Because of its multidisciplinary nature, nanoscience can require us to draw on knowledge in potentially unfamiliar academic fields. One day we may be dealing with nanomembranes and drug delivery systems, and the next day we may be talking about nanocomputing and semiconductors. At least some of the many areas that intersect with nanoscience are bound to be outside our areas of training and expertise.

… This provides an opportunity to engage and value our student knowledge beyond the traditional areas of chemistry.

While we may not have taken a biology or physics class in many years, chances are that at least some of our students have. We can acknowledge students' interest and expertise in these areas and take advantage of their knowledge. For example, ask a student with a strong interest in biology to connect drug delivery mechanisms to their knowledge about cell regulatory processes. In this way, we share the responsibility for learning and emphasize the value of collaborative investigation. Furthermore, this helps engage students whose primary area of interest isn't chemistry and gives them a chance to contribute to the class discussion. It also helps all students begin to integrate their knowledge from the different scientific disciplines and presents wonderful opportunities for them to see the how the different disciplines interact to explain real world phenomena.

Final Words

Nanoscience provides an exciting and challenging opportunity to engage our students in cutting edge science and help them see the dynamic and evolving nature of scientific knowledge. By embracing these challenges and using them to engage students in meaningful discussions about science in the making and how we know what we know, we are helping our students not only in their study of nanoscience, but in developing a more sophisticated understanding of the scientific process.

References

Luan, B., & Robbins, M. (2005, June). The breakdown of continuum models for mechanical contacts. *Nature 435*, 929-932.

Table 1. Challenges of teaching nanoscience and strategies for turning these challenges into learning opportunities.

	THE CHALLENGE…	PROVIDES THE OPPORTUNITY TO…
1	You will not be able to know all the answers to student (and possibly your own) questions ahead of time	Model the process scientists use when confronted with new phenomena: Identify and isolate questions to answer Work collectively to search for information using available resources (textbooks, scientific journals, online resources, scientist interviews) Incorporate new information and revise previous understanding as necessary Generate further questions for investigation
2	Traditional chemistry and physics concepts may not be applicable at the nanoscale level	Address the use of models and concepts as scientific tools for describing and predicting chemical behavior: Identify simplifying assumptions of the model and situations for intended use Discuss the advantages and limitations of using conceptual models in science Integrate new concepts with previous understandings
3	Some questions may go beyond the boundary of our current understanding as a scientific community	Involve students in exploring the nature of knowing: How we know what we know The limitations and uncertainties of scientific explanation How science generates new information How we use new information to change our understandings
4	Nanoscience is a multidisciplinary field and draws on areas outside of chemistry, such as biology and physics	Engage and value our student knowledge beyond the area of chemistry: Help students create new connections to their existing knowledge from other disciplines Highlight the relationship of different kinds of individual contributions to our collective knowledge about science Explore how different disciplines interact to explain real world phenomena

Size Matters: Overview and Learning Goals

Type of Courses:	Chemistry, physics, biology, interdisciplinary science
Grade Levels:	9-12
Topic Area:	The nanoscale perspective of physical properties
Key Words:	Nanoscience, nanotechnology, nanometer, size and scale, properties
Time Frame:	5-7 class periods (assuming 50-minutes classes), with extensions

Overview

This unit provides an introduction to nanoscience, focusing on concepts related to the size and scale, unusual properties of the nanoscale, and example applications of nanoscience.

Students will participate in learning activities that are designed to help them to establish an understanding of the nature of nanoscale science, the relative size of objects, unique properties of nanosized particles, and applications of nanoscience. They will read about these issues, complete worksheets, take quizzes, conduct laboratory investigations to understand properties of nanoscale objects, and create and present a poster comparing a current technology with a related nanotechnology.

As this is an introductory unit, many new terms will be introduced as students increase their understanding of the essential features of nanoscience. References to additional readings and curricular activities are provided so that the teacher can choose to include related topics as he or she determines is appropriate.

Enduring Understandings (EU)

What enduring understandings are desired? Students will understand:

1. The study of unique phenomena at the nanoscale could vastly change our understanding of matter and lead to new questions and answers in many areas, including health care, the environment, and technology.
2. There are enormous scale differences in our universe, and at different scales, different forces dominate and different models better explain phenomena.
3. Nanosized materials exhibit some size-dependent effects that are not observed in bulk materials.
4. New tools for observing and manipulating matter increase our abilities to investigate and innovate.

Essential Questions (EQ)

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

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?
3. Occasionally, there are advances in science and technology that have important and long-lasting effects on science and society. What scientific and engineering principles will be exploited to enable nanotechnology to be the next big thing?
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?

Key Knowledge and Skills (KKS)

What key knowledge and skills will students acquire as a result of this unit? Students will be able to:

1. Describe, using the conventional language of science, the size of a nanometer. Make size comparisons of nanosized objects with other small objects.
2. Explain why properties of nanoscale objects sometimes differ from those of the same materials at the bulk scale.
3. Describe an application (or potential application) of nanoscience and its possible effects on society.
4. Compare a current technology solution with a related nanotechnology-enabled solution for the same problem.
5. Explain how an AFM and a STM work, and give an example of their use.

Prerequisite Knowledge

This unit assumes that students are familiar with the following concepts or topics:

1. Atoms, molecules, cells, cell organelles, and protein molecules.
2. Basic units of the metric system and knowledge of prefixes.
3. How to manipulate exponential and scientific notation.
4. Some knowledge and experience with a light microscope.

NSES Content Standards Addressed

K-12 Unifying Concepts and Process Standard

As a result of activities in grades K-12, all students should develop understanding and abilities aligned with the following concepts and processes: (4 of the 5 categories apply)

- Systems, order, and organization
- Evidence, models and explanation
- Constancy, change, and measurement
- Form and function

Grades 9-12 Content Standard A: Science as Inquiry

Understandings about scientific inquiry

- **Scientists usually inquire about how physical, living, or designed systems function.** Conceptual principles and knowledge guide scientific inquiries. Historical and current scientific knowledge influence the design and interpretation of investigations and the evaluation of proposed explanations made by other scientists. (12ASI2.1)
- **Scientists rely on technology to enhance the gathering and manipulation of data.** New techniques and tools provide new evidence to guide inquiry and new methods to gather data, thereby contributing to the advance of science. The accuracy and precision of the data, and therefore the quality of the exploration, depends on the technology used. (12ASI2.3)

Grades 9-12 Content Standard B: Physical Science

Chemical reactions

- **Catalysts, such as metal surfaces, accelerate chemical reactions**. Chemical reactions in living systems are catalyzed by protein molecules called enzymes. (12BPS3.5)

Motions and forces

- **Between any two charged particles, electric force is vastly greater than the gravitational force.** Most observable forces such as those exerted by a coiled spring or friction may be traced to electric forces acting between atoms and molecules. (12BPS4.3)

Grades 9-12 Content Standard E: Science and Technology

Understanding about science and technology

- **Scientists in different disciplines ask different questions, use different methods of investigation, and accept different types of evidence** to support their explanations**.** Many scientific investigations require the contributions of individuals from different disciplines, including engineering. New disciplines of science, such as geophysics and biochemistry often emerge at the interface of two older disciplines. (12EST2.1)
- **Science often advances with the introduction of new technologies.** Solving technological problems often results in new scientific knowledge. New technologies often extend the current levels of scientific understanding and introduce new areas of research. (12EST2.2)
- **Science and technology are pursued for different purposes.** Scientific inquiry is driven by the desire to understand the natural world, and technological design is driven by the need to meet human needs and solve human problems. Technology, by its nature, has a more direct effect on society than science because its purpose is to solve human problems, help humans adapt, and fulfill human inspirations.

Technological solutions may create new problems. Science, by its nature, answers questions that may or may not directly influence humans. Sometimes scientific advances challenge people's beliefs and practical explanations concerning various aspects of the world. (12EST2.4)

Grades 9-12 Content Standard F: Science in Personal and Social Perspectives

Science and technology in local, national, and global challenges

- **Understanding basic concepts and principles of science and technology should precede active debate** about the economics, policies, politics, and ethics of various science - and technology - related challenges. However, understanding science alone will not resolve local, national or global challenges. (12FSPSP6.2)
- **Individuals and society must decide on proposals involving new research and the introduction of new technologies into society**. Decisions involve assessment of alternatives, risks, costs, and benefits and consideration of who benefits and who suffers, who pays and gains, and what the risks are and who bears them. Students should understand the appropriateness and value of basic questions - "What can happen?" - "What are the odds?" - and "How do scientists and engineers know what will happen? (12FSPSP6.4)

Grades 9-12 Content Standard G: History and Nature of Science

Historical perspectives

- **Occasionally, there are advances in science and technology that have important and long lasting effects on science and society**. Examples of such advances include the following: Copernican revolution, Newtonian mechanics, Relativity, Geologic time scale, Plate tectonics, Atomic theory, Nuclear physics, Biological evolution, Germ theory, Industrial revolution, Molecular biology, Information and communication, Quantum theory, Galactic universe, Medical and health technology. (12GHNS3.3)

AAAS Benchmark Standards

While some of the content of this unit does not map directly to the NSES, it does address the AAAS Benchmarks. Below we list the AAAS Benchmarks that this unit addresses that are not already addressed by the NSES.

Common Themes

- **11D Scale #1.** Representing large numbers in terms of powers of ten makes it easier to think about them and to compare things that are greatly different.
- **11D Scale #2.** Because different properties are not affected to the same degree by changes in scale, large changes in scale typically change the way that things work in physical, biological, or social systems.

Unit at a Glance: Suggested Sequencing of Activities by Day for the Full Set of Size Matters Curriculum Materials

Lesson	Teaching Day	Main Activities and Materials	Learning Goals	Assessment	Homework
	(Prep Day)	(Refer to individual lesson plans for detailed breakdown)			The Personal Touch: Student Reading and Worksheet Introduction to NanoScience: Student Reading
Introduction to Nanoscience	1 day	Class discussion on Personal Touch: Student Reading, Scale Diagram Introduction to Nanoscience: PowerPoint and Student Worksheet	EU 1, 4; EQ 1, 2, 4, 5, 6; KKS 1, 3	Worksheets for The Personal Touch and Intro to Nanoscience	Visualizing the Nanoscale: Student Reading
Scale of Objects	1 day	Number Line, Scale of Objects, or Cutting It Down Activity Class discussion and Scale Diagram	EU 2; EQ 1; KKS 1	Scale Activity Worksheets Scale of Small Objects Quiz	Size-Dependent Properties: Student Reading
Unique Properties at the Nanoscale	2 days: Day 1	Unique Properties at the Nanoscale: PowerPoint Prepare for Unique Properties Lab	EU 2, 3; EQ 2, 5; KKS 2		
	Day 2	Unique Properties Lab Activities & Student Worksheet		Lab Worksheet	Seeing and Building Small Things: Student Reading
Tools of the Nanosciences	2 days: Day 1	Scanning Probe Microscopy: PowerPoint Black Box Activity	EU 4; EQ 4, 5; KKS 5	Black Box Activity Worksheet	
	Day 2	Optional Extensions for Exploring Nanoscale Modeling	EU 4; EQ 4, 5	Unique Properties Quiz	
Applications of Nanoscience	4 days: Day 1	Applications of Nanoscience: PowerPoint	EU 1; EQ 3, 6;		Prepare for What's New Nanocat? Poster Session

Lesson	Teaching Day	Main Activities and Materials	Learning Goals	Assessment	Homework
		Assign What's New Nanocat Poster Session topics and groups	KKS 3, 4		
Applications of Nanoscience	Days 2-4	Preparation for What's New NanoCat Poster Session Group presentations		Presentation Scoring Rubric and Peer Feedback Form	

What **enduring understandings (EU)** are desired? Students will understand:

1. The study of unique phenomena at the nanoscale could vastly change our understanding of matter and lead to new questions and answers in many areas, including health care, the environment, and technology.
2. There are enormous scale differences in our universe, and at different scales, different forces dominate and different models better explain phenomena.
3. Nanosized materials exhibit some size-dependent effects that are not observed in bulk materials.
4. New tools for observing and manipulating matter increase our abilities to investigate and innovate.

What **essential questions (EQ)** will guide this unit and focus teaching and learning?

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?
3. Occasionally, there are advances in science and technology that have important and long-lasting effects on science and society. What scientific and engineering principles will be exploited to enable nanotechnology to be the next big thing?
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 ways that the discovery of a new technology can impact our lives?

What **key knowledge and skills (KKS)** will students acquire as a result of this unit? Students will be able to:

1. Describe, using the conventional language of science, the size of a nanometer. Make size comparisons of nanosized objects with other small objects.
2. Explain why properties of nanoscale objects sometimes differ from those of the same materials at the bulk scale.
3. Describe an application (or potential application) of nanoscience and it's possible effects on society.
4. Compare a current technology solution with a related nanotechnology-enabled solution for the same problem.
5. Explain how an AFM and a STM work; give an example of their use.

Alignment of Unit Activities with Learning Goals

Learning Goals	*Lesson 1: Intro to Nanoscience*	*Lesson 2: Scale of Objects*	*Lesson 3: Unique Properties*	*Lesson 4: Tools of the Nanosciences*	*Lesson 5: Applic. of Nanoscience*
Students will understand…					
EU 1. The study of unique phenomena at the nanoscale could vastly change our understanding of matter and lead to new questions and answers in many areas, including health care, the environment, and technology.	•				•
EU 2. There are enormous scale differences in our universe, and at different scales, different forces dominate and different models better explain phenomena.		•	•		
EU 3. Nanosized materials exhibit some size-dependent effects that are not observed in bulk materials.			•		
EU 4. New tools for observing and manipulating matter increase our abilities to investigate and innovate.	•			•	
Students will be able to…					
KKS1. Describe, using the conventional language of science, the size of a nanometer. Make size comparisons of nanosized objects with other small objects.	•	•			
KKS2. Explain why properties of nanoscale objects sometimes differ from those of the same materials at the bulk scale.			•		
KKS3. Describe an application (or potential application) of nanoscience and its possible effects on society.	•				•
KKS4. Compare a current technology solution with a related nanotechnology-enabled solution for the same problem.					•
KKS5. Explain how an AFM and a STM work; give an example of their use.				•	

Alignment of Unit Activities with Curriculum Topics

Chemistry

Unit Topic	Chapter Topic	Subtopic	Size Matters Lessons	Specific Materials
Nature of Chemistry	Tools of Science	Units & Measurement (size & scale)	• Lesson 1 (L1): Intro to Nanoscience • Lesson 2 (L2): Scale of Objects • Lesson 6 (L6): One Day Introduction	**Slides** • L1: 1-4 • L6: 1-8 **Activity/Handout** • L1 ○ Student Reading: Intro to Nanoscience ○ Worksheet: Intro to Nanoscience ○ Handout: scale diagram • L2 ○ Reading: Visualizing the Nanoscale ○ Card Sort/Number Line Activity ○ Scale of Objects Activity ○ Cutting it down activity ○ Quiz: Scale of small Objects
Structure of Matter	Electron Configuration	Quantum Theory	• Lesson 3 (L3): Unique Properties at the nanoscale	**Slides** • L3: 5, 6, 12, 14
Structure of Matter	Atomic Interactions	Chemical Reactions (precipitate formation, self-assembly)	• Lesson 1 (L1): Intro to Nanoscience	**Slides** • L1: 17-19 **Activity/Handout** • Reading: Intro to Nanoscience • Worksheet: Intro to Nanoscience
Nature of Chemistry	Tools of Science	Units & Measurement (size & scale)	• Lesson 1 (L1): Intro to Nanoscience • Lesson 2 (L2): Scale of Objects • Lesson 6 (L6): One Day Introduction	**Slides** • L1: 1-4 • L6: 1-8 **Activity/Handout** • L1 ○ Reading: Intro to Nanoscience ○ Worksheet: Intro to Nanoscience ○ Handout: Scale Diagram • L2 ○ Reading: Visualizing the Nanoscale ○ Card Sort/Number Line Activity ○ Scale of Objects Activity

				○ Cutting it down activity ○ Quiz: Scale of Small Objects
		Units & Measurement (Instruments)	• Lesson 1 (L1): Intro to Nanoscience • Lesson 2 (L2): Scale of Objects • Lesson 4 (L4): Tools of Nanoscience • Lesson 6 (L6): One Day Introduction	**Slides** • L1: 5-9 • L6: 11-14 **Activity/Handout** • L1 ○ Student Reading: Intro to Nanoscience ○ Worksheet: Intro to Nanoscience ○ Handout: Scale Diagram • L2 ○ Reading: Visualizing the Nanoscale ○ Cutting it down activity • L4 ○ Black Box Activity ○ Reading: Seeing & Building Small Things ○ Quiz

Biology

Unit Topic	Chapter Topic	Subtopic	Size Matters Lessons	Specific Materials
Nature of Life	Science of Biology	How Scientists Work	• Lesson 1 (L1): Introduction to Nanoscience	**Slides** • L1: 1-4 **Activity/Handout** • Scale Diagram: Discuss using question 1-2 from Intro to Nanoscience worksheet
		Studying Life	• Lesson 2 (L2): Scale of Objects	**Slides** • L1: 3 **Activity/Handout** • Number Line • Student Quiz • Reading: Visualizing the Nanoscale
		Tools and Procedure	• Lesson 4 (L4): Tools	**Slides** • L4: 1-11, 12 (optional) **Activity/Handout** • Black Box Lab Activity • Reading: Seeing and Building Small Things • Quiz
Nature of Life	The Chemistry of Life	The Nature of Matter; Properties of Water; Carbon Compounds	• Lesson 3 (L3): Unique Properties at the Nanoscale	**Slides** • L3: 1-17 **Activity/Handout** • Reading: Size-Dependent Properties • Unique Properties Labs • Student Quiz • Reading: The Personal Touch • Reading: Intro to Nanoscience
The Human Body	Nervous System	The Senses Drugs and the Nervous System	• Lesson 5 (L5): Applications of Nanoscience	**Slides** L5: 1-2, 9
The Human Body	Circulatory and Respiratory Systems	The Circulatory System	• Lesson 5 (L5): Applications of Nanoscience	**Slides** L5: 1-2, 11
	The Immune System and Disease	Infectious Disease		**Slides** L5: 1-2, 12
		Cancer		**Slides** L5: 1-2, 10

Extensions	Bioethics	Use of Nanotechnology in the Human Arena	**Size Matters** • Lesson 5 (L5): Applications of Nanoscience	Any topics covered in L5 or any students may have considered

Physics

Unit Topic	Chapter Topic	Subtopic	Size Matters Lessons	Specific Materials
Mechanics	Measurement	Length/mass/time Units/order of magnitude	• Lesson 1 (L1): Intro to Nano • Lesson 2 (L2): Scale of Objects • Lesson 6 (L6): One Day Introduction	**Slides** • L1: 2-3 • L6: 2-3 **Activity/Handout** • L2 ○ Card Sort/Number Line ○ Scale Diagram ○ Cutting it Down
		Electrostatic forces	• Lesson 4 (L4): Tools of the Nanosciences • Lesson 6 (L6): One Day Introduction	**Slides** • L4: 2, 8 • L6: 24
Electricity and Magnetism	Current and Resistance	Classical vs. Modern Physics (e.g., different dominant forces, different "rules" at nano/atomic scale)	• Lesson 3 (L3): Unique Properties at the Nanoscale	**Slides** • L3: (most)

Environmental Science

Unit Topic	Chapter Topic	Subtopic	Size Matters Lessons	Specific Materials
Water	Using Science to Solve Environmental Problems	What is Science	• Lesson 1 (L1): Intro to Nanoscience • Lesson 2 (L2): Scale of Objects • Lesson 3 (L3): Unique Properties at the Nanoscale	**Slides** • L1: 1-4 • L3: 1-17 **Activity/Handout** • L1 ○ Scale Diagram •Have students discuss and question diagram using questions 1-2 from student worksheet • L2 ○ Number Line ○ Student Quiz ○ Reading: Visualizing the Nanoscale ○ Student Quiz • L3 ○ Reading: Size-Dependent Properties ○ Labs A-H, any combination of labs as instructor sees fit ○ Student Quiz ○ Reading: The Personal Touch ○ Reading: Intro to Nanoscience

Size Matters Pretest/Posttest: Teacher Answer Sheet

20 points total

1. How big is a nanometer compared to a meter? List one object that is nanosized, one that is smaller, and one that is larger but still not visible to the naked eye. (1 point each, total of 4 points)

A nanometer is one billionth of a meter (or 10^{-9} m in scientific notation).

Sample nanosized objects:

- Virus, DNA strand (diameter), Ribosome, Hemoglobin, Sucrose molecule
- Carbon nanotube (diameter), Buckyballs
- Some enzymes (e.g. ATP synthase), some "molecular motors" (e.g. kinesin)
- Photosynthetic machinery in plants and bacteria,

Sample objects that are smaller:

- Water molecule
- Atoms
- Sub-atomic particles (protons, neutrons, electrons)

Sample objects that are larger than but still not visible to the naked eye:

- Bacteria, Ameoba
- Human egg cell, Human sperm cell
- Red blood cell

2. Name two properties that can differ for nanosized objects and much larger objects of the same substance. For each property, give a specific example. (2 points each, total of 4 points)

Optical properties (such as color and transparency):

- Bulk gold appears yellow in color, nanosized gold appears red in color.
- Regular zinc oxide appear white on the skin, the nano-version appears clear.

Electrical properties (such as conductivity):

- Carbon nanotubes conductivity change with diameter, "twist," and number of walls.
- Physical properties (such as density and boiling point).
- Nanoparticles have lower melting and boiling points b/c there is a greater percentage of atoms at the surface (require less energy to overcome intermolecular attractions).

Chemical properties (such as reactivities and reaction rates):

- Nanoparticles have a greater percentage of atoms at the surface and thus greater reactivities (students may mention any of the examples of this done in the labs).

3. Describe two reasons why properties of nanosized objects are sometimes different than those of the same substance at the bulk scale. (2 points each, 4 points total)

Dominance of electromagnetic forces:

- 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.

Quantum effects:

- At very small scale, the classical mechanical models that we use to understand matter at the macroscale don't work.
- The quantum mechanical model that does help us understand matter is based on probability, not certainty and unusual results such as quantum tunneling (when an electron can "pass through" an energy barrier) may occur.

Surface to volume ratio:

- As surface area to volume ratio increases, a greater amount of a substance comes in contact with surrounding material, this increase reaction rates.

Random molecular motion:

- While random molecular motion (molecules moving around in space, rotating around their bonds, and vibrating along their bonds) is present for all particles, at the macroscale this motion is very small compared to the sizes of the objects and thus is not very influential in how object behave.
- At the nanoscale however, these motions can be on the same scale as the size of the particles and thus have an important influence on how particles behave.

4. What do we mean when we talk about "seeing" at the nanoscale? (2 points)

- "Seeing" an object means using a tool that interacts with the object to produce some representation of it (often an image).
- While many common tools use the interaction between visible light and an object to create a representation, at the nanoscale the objects we want to "see" are smaller than the wavelengths of visible light so this approach is not useful.
- To "see" at the nanoscale, we need to use tools that leverage other kinds of interactions with the surface of the object (like electrical and magnetic forces) to create a representation of the object.

5. Choose one technology for seeing at the nanoscale and briefly explain how it works. (3 points)

Atomic Force Microscope (AFM) • Uses a tiny tip that moves in response to the electromagnetic forces between the atoms of the surface and the tip. • Either measures the tiny upward and downward movement of the tip necessary to remain in close contact with the surface or makes the tip vibrate to tap the surface and senses when contacts is made. • In both bases, the signals (forces or contact) change based on the features of the object's surface (height, angle etc.) and are used to infer a topographical image of the object. Scanning Tunneling Microscope (STM) • Uses a fine tip that can conduct electricity; the nano-object to be imaged must also conduct electricity. • The tip is put very near, but not touching the object surface and the "tunneling" of electrons between the tip and the atoms of the object's surface being creates a flow of electrons (a current). • The signals (current) changes based on the features of the object's surface (height, angle etc.) and are used to infer a topographical image of the object.

6. Describe one application (or potential application) of nanoscience and its possible effects on society. (3 points)

Existing Applications Include: • Stain Resistant Clothes: Fine-spun fibers ("nanowhiskers") are embedded into fabrics and act like peach fuzz to create a cushion of air around the fabric so that liquids bead up and roll off. This innovation will leads to less stains, less need for washing clothes (using detergent) and dry cleaning (using chemicals), and even less need to replace (and thus produce clothing). These could all have positive impacts on the environment. • Nano Solar Cells: Traditional solar cells provide one source of clean energy but they are expensive to produce. A new kind of solar cells use nanoparticles of TiO_2 coated with dye molecules to capture the energy of visible light and convert it into electricity. These solar cells are less expensive to produce and have the potential to be used in a wide range of applications. • Clear Sunscreen: Traditional inorganic sunscreens (ZnO and TiO_2) provide powerful protection from the full range of UV light, but are often not used or under-applied because they appear white on the skin (due to the scattering of visible light). ZnO and TiO_2 nanoparticles provide the same UV protection as their larger counterparts, but are so small that they don't scatter visible light and thus appear clear on the skin.

Existing Applications (continued)

- Building Smaller Devices and Chips: A technique called nanolithography lets us create much smaller devices than current approaches. This technique can be used to further miniaturize the electrical components of microchips. Dip pen nanolithography is a 'direct write' technique that uses an AFM to create patterns and to duplicate images. "Ink" is laid down atom by atom on a surface, through a solvent—often water.
- Health Monitoring: Several nano-devices are being developed to keep track of daily changes in patients' glucose and cholesterol levels, aiding in the monitoring and management of diabetes and high cholesterol for better health. For example, some researchers have created coated nanotubes in a way that will fluoresce in the presence of glucose. Inserted into human tissue, these nanotubes can be excited with a laser pointer and provide real-time monitoring of blood glucose level.

Potential Applications Include:

- Paint That Cleans the Air: A titanic-oxide-based compound in nanosized particles has been claimed to clean the air by decomposing the major ingredients that cause air pollution such as formaldehyde and nitride. This compound could be used in paints, acting as a permanent air purifier and helping to improve the air quality in polluted areas.
- "Paint-On" Solar Cells: Scientists are trying to develop a photovoltaic material using semiconducting nanorods that can be spread like plastic wrap or paint. These nano solar cells could be integrated with other building materials, and offer the promise of cheap production costs that could finally make solar power a widely used electricity alternative.
- Drug Delivery Systems: Nanotubes and buckyballs could serve as drug delivery systems. Because they are inert and small enough to cross many membranes, including the blood-brain barrier, they could be used to carry reactive drugs to the right part of the body and "deliver" the drug inside the appropriate cell.
- Water Treatment: Advanced nanomembranes could be used for water purification, desalination, and detoxification, nanosensors could detect contaminants and pathogens, and nanoparticles could degrade water pollutants and make salt water and even sewage water easily converted into usable, drinkable water. This could help address water crises across the plant.
- Clean Energy: Hydrogen fuel is currently expensive to make, but with catalysts made from nanoclusters, it may be possible to generate hydrogen from water by photocatalytic reactions. Novel hydrogen storage systems could be based on carbon nanotubes and other lightweight nanomaterials, nanocatalysts could be used for hydrogen generation, and nanotubes could be used for energy transport.
- Detecting Disease with Quantum Dots: Quantum dots are small cadmium-based devices that contain a tiny droplet of free electrons, and emit photons when submitted to ultraviolet (UV) light. Scientists are exploring ways to seal the dots in polymer capsules to protect the body from cadmium exposure; the surface of each capsule can then be designed to attach to different harmful molecules (for example those indicating presence of cancer). As the dots collect in a tumor, they become visible in ultraviolet light under a microscope, allowing doctors to identify and locate cancer earlier.

Unit Overview

Student Materials

Contents

Name_________________________________ Date_____________________ Period ______

Size Matters: Pretest

1. How big is a nanometer compared to a meter? List one object that is nanosized, one that is smaller, and one that is larger but still not visible to the naked eye.

2. Name two properties that can differ for nanosized objects and much larger objects of the same substance. For each property, give a specific example.

3. Describe two reasons why properties of nanosized objects are sometimes different than those of the same substance at the bulk scale.

4. What do we mean when we talk about "seeing" at the nanoscale?

5. Choose one technology for seeing at the nanoscale and briefly explain how it works.

6. Describe one application (or potential application) of nanoscience and its possible effects on society.

Name_________________________________ Date_____________________ Period ______

Size Matters: Posttest

1. How big is a nanometer compared to a meter? List one object that is nanosized, one that is smaller, and one that is larger but still not visible to the naked eye.

2. Name two properties that can differ for nanosized objects and much larger objects of the same substance. For each property, give a specific example.

3. Describe two reasons why properties of nanosized objects are sometimes different than those of the same substance at the bulk scale.

4. What do we mean when we talk about “seeing” at the nanoscale?

5. Choose one technology for seeing at the nanoscale and briefly explain how it works.

6. Describe one application (or potential application) of nanoscience and its possible effects on society.

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.

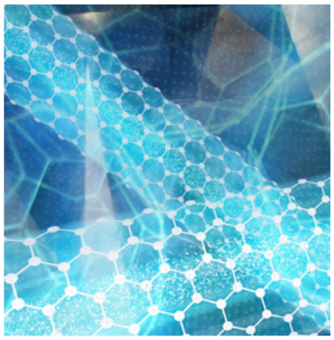
Prerequisite Knowledge and Skills

- 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

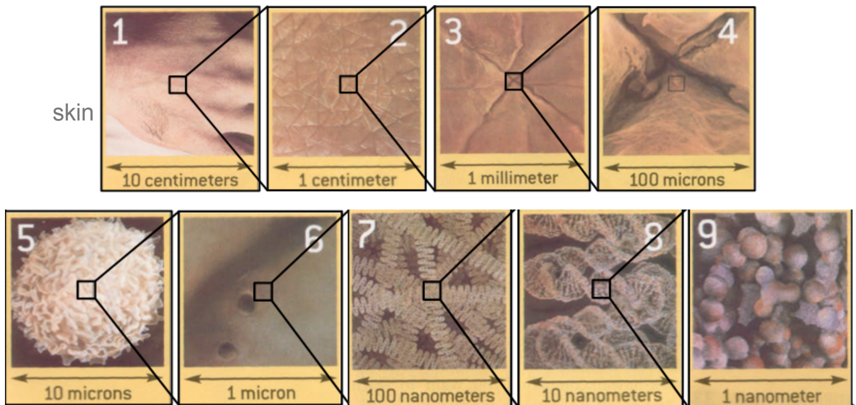
What is Nanoscale Science?

- **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

How Big is a Nanometer?

- **Consider a human hand**



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

Are You a Nanobit Curious?

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

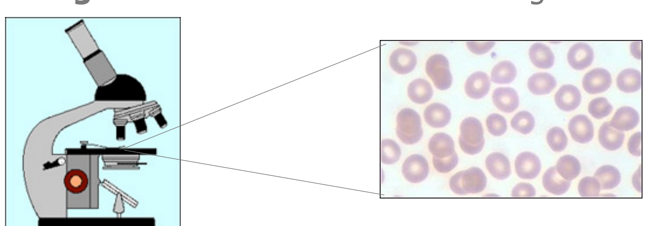
So How Did We Get Here?

New Tools!

As tools change, what we can see and do changes

Using Light to See

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

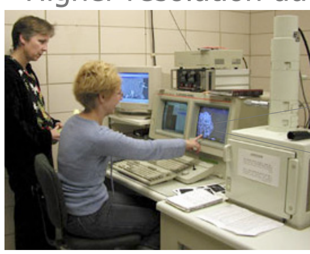


Light microscope (magnification up to 1000x) → to see red blood cells (400x)

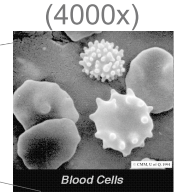
Sources: http://www.cambridge.edu.au/education/PracticeITBook2/Microscope.jpg
http://news.bbc.co.uk/olmedia/760000/images/_764022_red_blood_cells300.jpg

Using Electrons to See

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



(4000x)

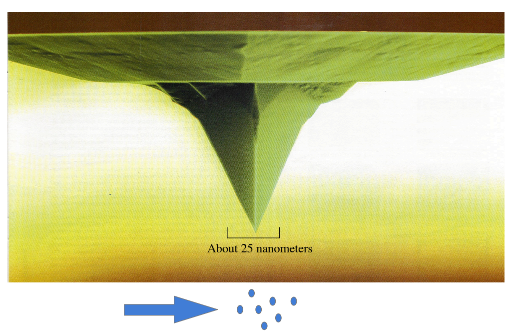


Greater resolution to see things like blood cells in greater detail

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

Touching the Surface

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

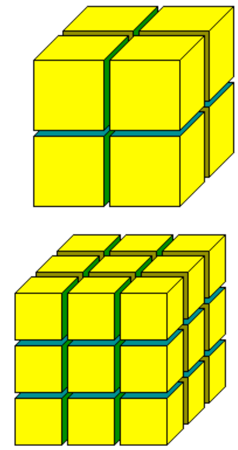
Is nanoscience just seeing and moving really small things?

- **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"?

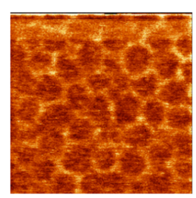


Source: http://www.uwgb.edu/dutchs/GRAPHIC0/GEOMORPH/SurfaceVol0.gif

NanoSense 12

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

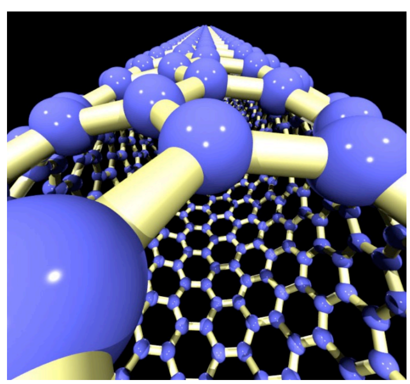
Nanostructures

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



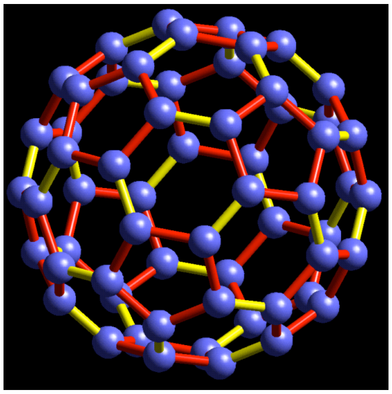
Model of a carbon nanotube

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

NanoSense 15

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)



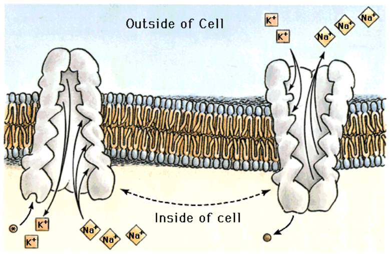
Model of Buckminsterfullerene

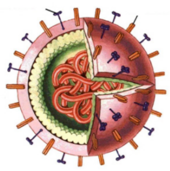
Source: http://digilander.libero.it/geodesic/buckyball-2Layer1.jpg

NanoSense 16

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

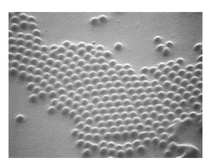
Building Nanostructures

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

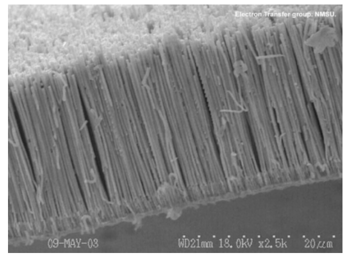

Polystyrene spheres self-assembling

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

NanoSense 19

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.

Lesson 1:
Introduction to Nanoscience

Student Materials

Contents

Introduction to Nanoscience: Student Reading

What is Nanoscience?

Way back in 1959, a physicist named Richard Feynman shared his vision of what very small things would look like and how they would behave. In a speech at the California Institute of Technology titled "There's Plenty of Room at the Bottom," Feynman gave the first hint about what we now know as "**nanoscience**" [1]:

> "The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things **atom** by atom."

More generally, nanoscience is the study of the behavior of objects at a very small scale, roughly 1 to 100 **nanometers** (nm). One nanometer is one billionth of a meter, or the length of 10 hydrogen atoms lined up. Nanosized structures include the smallest of human-made devices and the largest **molecules** of living systems.

What is the Big Deal About Nanoscience?

You might ask, "What is the big deal with nanoscience? Isn't it just a bunch of really small things?" It is, in fact, a bunch of small things. But it is a whole lot more. What makes the science at the nanoscale special is that at such a small scale, while all physical laws affect the behavior of matter, different laws dominate over those that we experience in our everyday lives. For example, the **element** gold (Au) as we are used to seeing it has a nice yellowish-brown color to it—the color we know as "gold." However, if you had only 100 gold atoms arranged in a cube, this block of gold would look very different—its color would be much more red. Color is just one property (optical) that is different at the nanoscale. Other properties, such a flexibility/strength (mechanical) and **conductivity** (electrical) are often very different at the nanoscale as well.

Surface Area is Big!

The smaller something is, the larger its surface area is compared to its volume. This high surface-to-volume ratio is a very important characteristic of **nanoparticles**.

For example, imagine that you have a big block of ice with one-meter sides (see Figure 1). This block has a surface area of 6 square meters (1 square meter on a side x 6 sides) and a volume of 1 cubic meter. In this case, the surface area to volume ratio for the ice block is 6/1 or 6.

Suppose that cut the ice into 8 pieces that are one-half of a meter per side. The surface area of each piece of ice would be 1.5 square meters (0.5 m x 0.5 m x 6 sides). So the total surface area of all the pieces would be 12 square meters. However, the total volume of ice would stay the same: we haven't added or removed any ice. So in this case, the surface area to volume ratio is 12/1, or 12—twice the surface area to volume ratio of the block before it was cut. If you cut the ice into 27 pieces, the surface area increases to 18 square meters, and the surface area to volume ratio is 18/1 or three times that of the uncut block. If you keep going, and cut the ice into 1000 small pieces, the surface area to volume ratio is 60/1 or ten times that of the uncut block!

Imagine how big the surface area to volume ratio would be for something as small as a bunch of **nanoscale** particles.

The vastly increased ratio of surface area to volume makes interactions between the surfaces of particles very important. If something has more surface area, there are more places for other chemicals to bind or react with it. For example, fine powders offer greater reaction speed because of the increased surface area. Think about how much faster you can cool a glass of water if you put crushed ice in it rather than ice cubes.

Nanoscale particles maximize surface area, and therefore maximize possible **reactivity**!

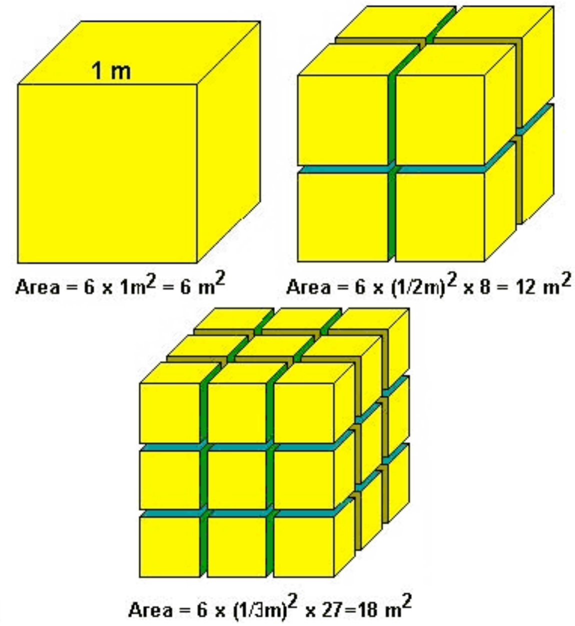


Figure 1. Total surface area increases as you cut the block into smaller pieces, but the total volume stays constant [2].

Why is Large Surface Area Important?

The large surface area to volume ratio of nanoparticles opens many possibilities for creating new materials and facilitating chemical processes. In conventional materials, most of the atoms are not at a surface; they form the bulk of the material. In **nanomaterials**, this bulk does not exist. Indeed, **nanotechnology** is often concerned with single layers of atoms on surfaces. Materials with this property are unique. For example, they can serve as very potent **catalysts** or be applied in thin films to serve as thermal barriers or to improve wear resistance of materials.

Can We Make Small Devices?

Yes indeed. Over the past few decades, there have been many attempts to create devices at a small scale. If you look at the evolution of technology all around us, you'll notice that it's continually getting smaller.

Back in 1965, Gordon E. Moore (co-founder of Intel) observed that the number of **transistors** squeezed onto a computer chip roughly doubles every 18 months. This "rule" is known as "Moore's Law." The more transistors on a chip, the smaller their size and closer their spacing (see Figure 2). And as size decreases, speed and performance rise rapidly. This is why computers the size of a room in the 1950s now fit on your lap.

Indeed, many modern-day electronics already contain nanoscale-size components. For the **semiconductor** industry (Figure 2), nanotechnology has been the result of a continuous series of improvements in processing and materials over decades. Moore's Law won't last forever, though. At some point, the laws of physics will make it impossible to keep downsizing microelectronics at this exponential rate. Why? Because eventually, you get down to manipulating individual molecules, and at that level, a few atoms out of place could ruin an entire computer chip. The packed-in transistors also generate a lot of heat, which could melt the chip. Engineers are looking to nanoscience for tools and materials to enable computer chip manufacturing on an atomic scale. [4]

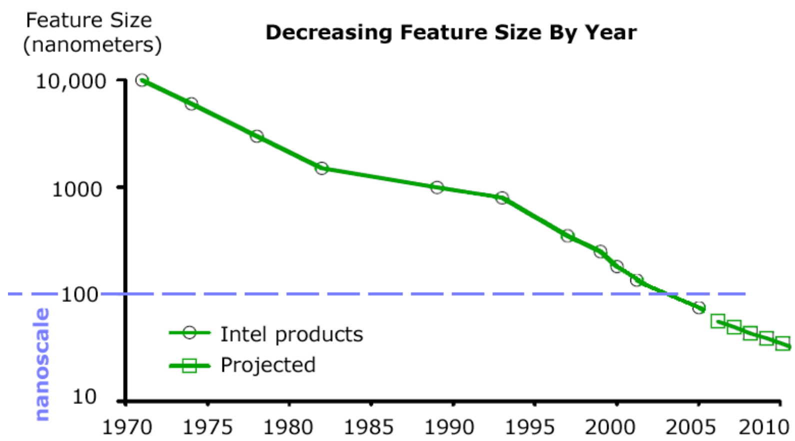


Figure 2. The decreasing minimum feature size of transistor components [3]. Note that size is graphed on a logarithmic scale, so the change is exponential.

Another group of devices that are considered small, but not quite at the nanoscale, are **MEMS (micro-electro-mechanical systems)** devices. Imagine machines built to the scale of microns, with gears, motors, levers, and so on, which are capable of moving things. One useful application of MEMS devices is in tiny acceleration **sensors** that quickly deploy the airbags in your car during an accident.

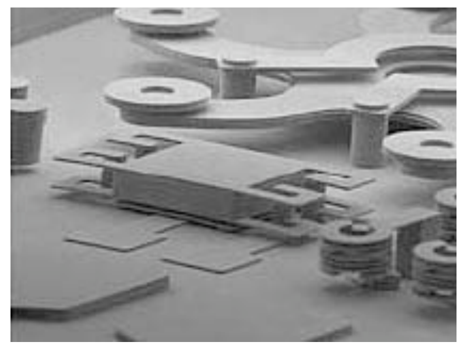


Figure 3. MEMS accelerometer [5].

What Kind of Nanostructures Can We Make?

Two interesting structures that have been constructed and fall into the nanoscale range are carbon nanotubes and buckyballs. You'll find these structures mentioned in almost any book or article on nanotechnology. Like diamond, carbon nanotubes and buckyballs are constructed solely out of carbon atoms. (Because carbon bonds so strongly to itself, it is a natural for use in nanotechnology.) What is most interesting about these two structures is that they possess some very unusual **chemical** and **physical properties**.

What is a Carbon Nanotube?

Carbon nanotubes are cylindrical carbon molecules with interesting properties. For example, they can be made to be excellent **electrical conductors** or **semiconductors** just by controlling how they are formed ("rolled"). With traditional materials, you have to add chemicals or elements to them to make them behave as conductors. With nanotubes, you just twist them! Another unique property of nanotubes is that they are very resilient and flexible, as well as extremely strong. We also know that nanotubes are very "**hydrophobic**"—they don't like water—and that they bind easily to proteins. Because of this last property, they can serve as chemical and biological sensors by being sensitive to certain molecules but not others by coating them in different ways. Nanotubes can also be made from elements other than carbon, such as gold and silver. Although they are not as strong as carbon nanotubes, they also have unique electrical and optical properties.

How Could Nanotubes be Used?

Carbon nanotubes have been used in a wide variety of products. For example, Toyota uses a carbon-nanotube-based composite in the bumpers and door panels of some of its cars, not only to make them stronger and lighter but also to make painting them easier since carbon nanotubes make the plastic electrically conductive so that the same electrically bonding paints that are used on metal parts can be applied.

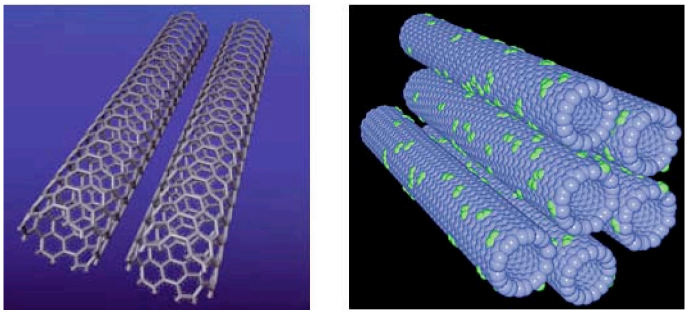


Figure 4. Computer-generated models of carbon nanotubes [6, 7].

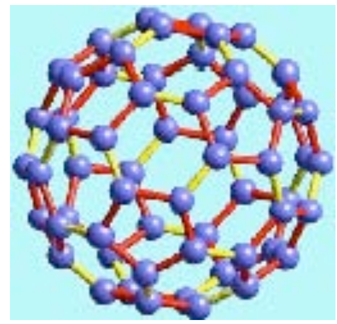


Figure 5. Model of a buckyball with single bonds (red) and double bonds (yellow) highlighted [8].

What is a Buckyball?

Buckyballs also have a unique set of properties that are based on their structure. Notice how the molecular model of the buckyball looks like a soccer ball. The usual structure for this molecule is made of 60 carbon atoms arranged in a soccer ball-like shape that is less than one nanometer in diameter. Because of the “hollow-ball” shape of this structure, scientists are currently testing to see how effective buckyballs are as drug carriers in the body. The hollow structure can fit a molecule of a particular drug inside, while the outside of the buckyball is resistant to interaction with other molecules in the body. Even though much more research is needed in this area, buckyballs appear to be relatively safe functional drug “containers” that can enter cells, without reacting with them.

What Nanostructures Exist in Nature?

There are many natural nanoscale devices that exist in our biological world. Some examples are **ion pumps**, “molecular motors,” and photosynthetic processes. 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, such as **neurotransmitters**, have to be specifically transported around cells and across membranes. The classic example of an active ion pump is in the **enzyme** ATP synthase. In this enzyme, the a central protein structure rotates as ATP is synthesized and ions are moved across a cellular membrane.

Another example is kinesin. Kinesin is a molecular motor that transports larger particles around cells on microtubules. The kinesin molecule acts like a train car on a microtubule nanosized track to carry **proteins** and larger particles to specific sites in cells. The

photosynthetic machinery in plants (chloroplast) and bacteria is also a complex nanomachine. It includes a light-harvesting component, a reaction center, and an ion pump, all arranged in a specific layout within the cell membrane that allows for the conversion of light into energy that the plant can use.

So How Do We "See" These Small Things?

As the field of nanoscience has grown, new tools have made it easier for scientists to see, image, and manipulate atoms and molecules. One type of microscope that works at the nanoscale is the **scanning tunneling microscope (STM)** which was developed in 1981. The very end of the tip of this microscope is one atom in size. The "tunneling" of electrons (**quantum tunneling**) between the tip and the substance being viewed creates a current (flow of electrons). The strength of the current and how it changes over time can be used to create an image of the surface of the substance. Today's scanning microscopes can do much more than just see. Among other things, they can be used to move atoms around and arrange them in a preferred order.

A different type of microscope, the **atomic force microscope (AFM)**, uses a tiny tip that moves in response to the **electromagnetic forces** between the atoms of the surface and the tip. As the tip moves up and down, the motion is recorded and an electronic image of the atomic surface is formed.

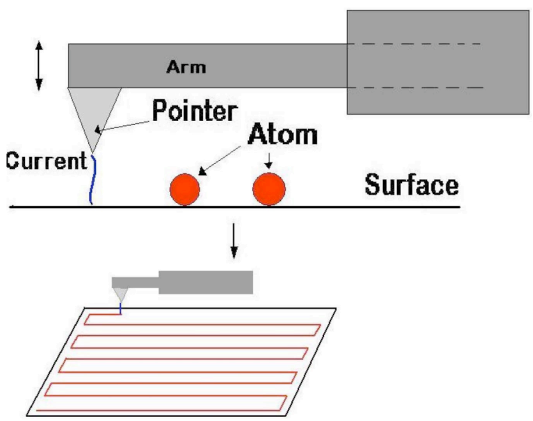


Figure 6. Schematic of a scanning tunneling microscope [9].

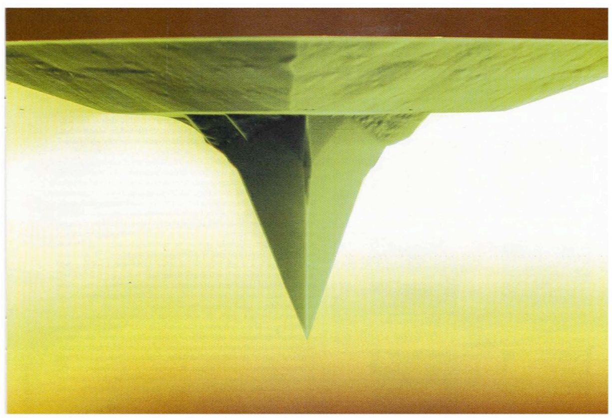


Figure 7. Tip of an atomic force microscope [10].

How Do You Build Things That Are So Small?

Building nanoscale devices isn't quite as straightforward as simply making your tools smaller and using powerful microscopes. When you are dealing with objects at this scale, things literally start to become very "sticky." Nanoparticles are attracted to each other via electrostatic forces, and this effect makes it very hard to handle and move things that are very, very small.

However, this difficulty hasn't stopped advances in how scientists and engineers build or fabricate nanomaterials. Here are the main nanofabrication techniques that are used to build small things:

1. Atom-by-Atom Assembly

Assembly atom-by-atom is similar to bricklaying in that atoms are moved into place one at a time using tools like the STM and AFM. Using this technique, scientists have, for example, positioned xenon atoms on nickel and buckyballs on copper to create nanoscale structures like the IBM logo and nanoscale abacus shown below. As you might guess, building structures one atom at a time is very time consuming. Examples of this type of assembly have typically been "proof of concept" to show that it can be done but don't necessarily have practical application because the process is expensive and slow.

Figure 8. IBM logo assembled from individual xenon atoms arranged on a nickel surface [11].

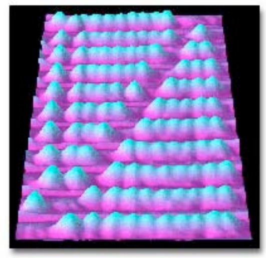


Figure 9. Nanoscale abacus buckyball "beads" placed on a copper surface [12].

2. Chisel Away Atoms

Imagine taking a block of wood or stone and carving it away to create an object that you want. The smallest features you can create depend on the tools you use.

Like sculptors, scientists can also chisel out material from a surface until the desired structure emerges. The computer industry uses this approach when they create integrated circuits. They use a process called photolithography, in which patterned areas of material are etched away through physical or chemical processes.

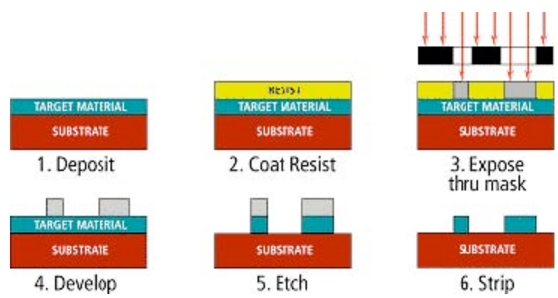


Figure 10. Photolithography, a process of chiseling away material to make integrated circuits [13].

3. Self-Assembly

Self-assembly means setting up an environment such that atoms assemble or grow automatically on prepared surfaces. In this approach, an environment is created in which structures assemble automatically. Examples include chemical vapor deposition and the patterned growth of nanotubes. Nature, of course, uses self-assembly mechanisms, such as the self-assembly of cell membranes. Our ability to create nanostructures improves as we gain understanding of biological self-assembly, develop new molecular structures, and construct new tools.

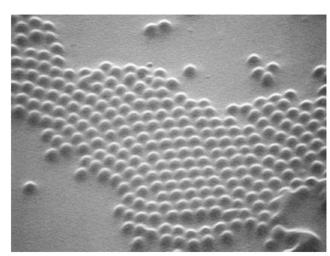


Figure 11. Polystyrene spheres self-assembling [14].

Summary

Although substances have existed for a long time that are composed of nanosized particles, it has been only after the invention of the new AFM and STM category of microscopes that we have been able to observe, gather data on, and even manipulate molecules and atoms. We are discovering that when molecules and atoms assemble into particles between 1 and 100 nanometers in size, different laws dominate at that scale than in our everyday experience of objects. Unique properties begin to emerge for substances at the nanoscale, including unique optical, mechanical, electrical, and thermal properties.

Nanoscale science is an exciting area of current research. Applications in information technology, medicine, composite materials, and other fields, are now open for further exploration. Nanoscience is emerging as a way to describe the behavior of substances in biology, chemistry, physics, earth science, metrology, medicine, and engineering. It is a truly interdisciplinary field that can be the basis for the development of new, even revolutionary technologies of all kinds. These little particles and devices may soon have a huge impact on our daily lives.

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Glossary

Term	Definition
atom	The smallest particle of an element that retains the chemical identity of the element; made up of negatively charged electrons, positively charged protons, and uncharged neutrons.

atomic force microscope (AFM)	A high-powered instrument able to image surfaces to molecular accuracy by mechanically probing their surface contours.
catalyst	A material that speeds up a chemical reaction without being used itself.
chemical property	A characteristic of a substance that cannot be observed without altering the identity of the substance, only can be observed when substances interact with one another.
chemical bond	A mutual attraction between different atoms that bonds the atoms together.
conductor	A material that contains movable charges of electricity. When an electric potential difference is impressed across separate points on a conductor, the mobile charges within the conductor are forced to move, and an electric current between those points appears in accordance with Ohm's law.
electrical conductivity	The current (movement of charged particles) through a material in response to electrical forces. The underlying mechanism for this movement depends on the type of material.
electrical conductor	A material that contains charges that can move freely throughout the material. When these charges are forced to move in a regular pattern from one point towards another (due to an electrical force), this movement is called a current.
electrical insulator	A material that does not allow electricity to flow through it.
electromagnetic forces	Particles with charge (or areas of charge) exert attractive or repulsive forces on each other due to this charge. Particles with magnetic properties exert attractive or repulsive forces on each other due to these magnetic properties. Since magnetism is caused by charged particles accelerating (for example by the electron "spin" in materials such as iron), these forces are considered to be two aspects of the same phenomenon and are collectively called electromagnetic forces.
electrostatic force	The attractive or repulsive force between two particles as a result of their charges. Like charges repel, unlike or different charges attract. The size of the force increases as the amount of charge on the particle increases, and the force rapidly decreases as the distance between the two particles increase.
element	A substance that cannot be separated into simpler substances by a chemical change; simplest type of pure substance.
enzyme	A protein that catalyzes a chemical reaction.
hydrophobic	Water repelling.

ion pump	A mechanism of active transport that moves potassium ions into and sodium ions out of a cell.
MEMS (micro-electro-mechanical systems)	A technology that combines computers with tiny mechanical devices such as sensors, valves, gears, mirrors, and actuators embedded in semiconductor chips.
molecule	The smallest particle of a substance that retains all of the properties of the substance and is composed of two or more atoms bonded by the sharing of electrons.
nanomaterial	A material with an average grain size less than 100 nanometers.
nanometer	One-billionth of a meter (10-9m). The prefix 'nano' is derived from the Greek word for dwarf because a nanometer is very small. Ten hydrogen atoms lined up side-by-side are about 1 nanometer long.
nanoparticle	A microscopic particle whose size is measured in nanometers.
nanoscale	Refers to objects with sizes in the range of 1 to 100 nanometers in at least one dimension.
nanoscience	The study of phenomena at the nanoscale (e.g. atoms, molecules and macromolecular structures), where properties differ significantly from those at a larger scale.
nanotechnology	The design, characterization, production and application of structures, devices and systems that take advantage of the special properties at the nanoscale by manipulating shape and size.
neurotransmitter	A chemical substance responsible for communication among nerve cells. Typically reside in sacs at the end of an axon that carries nerve impulses across a synapse.
physical property	Properties that can be measured without changing the composition of a substance, such as color and freezing point.
photosynthesis	A biochemical process in which cells in plants, algae, and some bacteria use light energy to convert inorganic molecules into ATP, a source of energy for cellular reactions.
protein	A compound whose structure is dictated by DNA. Proteins perform a wide variety of functions in the cell including serving as enzymes, structural components, or signaling molecules.
quantum tunneling	A phenomenon in which a very small particle passes through an energy state that is "classically-forbidden" (meaning that it is not possible based on Newton's laws of physics). Another way of saying this is that the particles can pass through barriers that should be impenetrable and be found in places that Newton's

	laws would predict to be impossible. The classical analogy is for a car on a roller coaster to make it up and over a hill that it does not have enough kinetic energy (energy of motion) to surmount.
reactivity	A substance's susceptibility to undergoing a chemical reaction or change that may result in side effects, such as an explosion, burning, and corrosion or toxic emissions.
scanning tunneling microscope (STM)	A machine capable of revealing the atomic structure of particles. The microscope uses a needle-like probe to extend a single atom near the object under observation. When the probe is close enough, an electromagnetic current can be detected. The probe then sends a tiny voltage charge. This charge creates an effect known as tunneling current. The tunneling current is measured by scanning the surface of the object and mapping the distance at various points, generating a 3D image. Scanning tunneling microscopes have also been used to produce changes in the molecular composition of substances.
semiconductor	A solid material whose electrical conductivity is greater than an **electrical insulator** but less than that of a good **electrical conductor**. The conductivity of semiconductors can also be manipulated by "doping" - adding certain impurities that change the ways electrons can travel through the material. This makes semiconductors a useful material for computer chips and other electronic devices
sensor	A device, such as a photoelectric cell, that receives and responds to a signal or stimulus.
transistor	A tiny device that turns the flow of electrons on and off to regulate electricity in a circuit. This on/off ability is used to represent binary digits, the digital data used for storing and transmitting information in a computer.

Name________________________________ Date_____________________ Period ______

Introduction to Nanoscience: Student Worksheet

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"?

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

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?

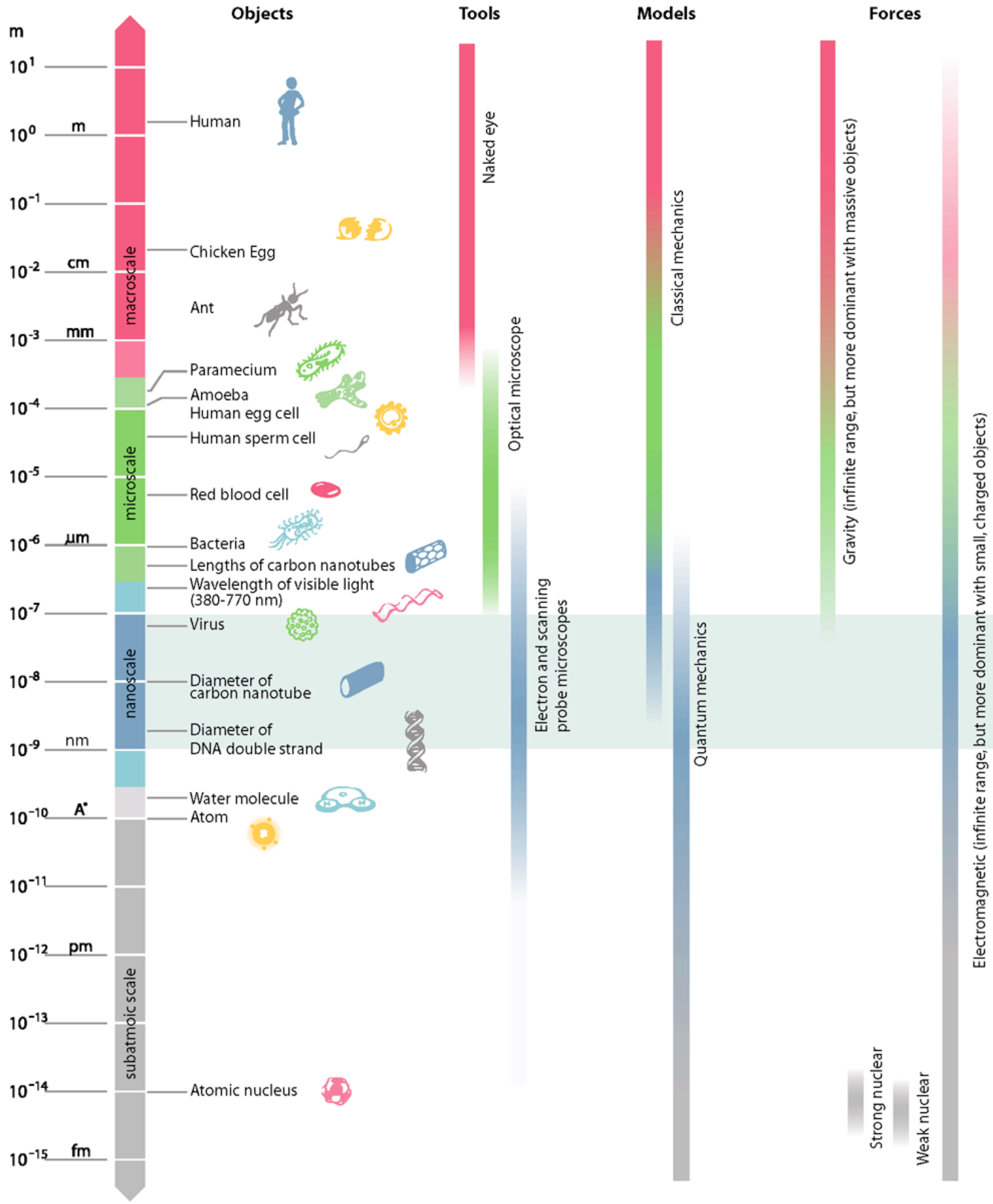
4. Briefly describe how light microscopes and electron microscopes work.

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.

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

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

Scale Diagram: Dominant Objects, Tools, Models, and Forces at Various Different Scales



The Personal Touch (Prom Day, 2045 A.D.): Student Reading

"So, Aladdin, how'm I doin'?" Sandra asked the household artificial intelligence (AI) as she walked into the bathroom.

Recognizing her unique voiceprint, the system answered, "Sandra, if you place your hand on the wall panel, I'll do a quick checkup."[1]

"OK," Sandra slapped her hand against the panel, "and you can start the shower for me."

"Sandra," the bathroom said, "you should take a "C" tablet after you finish your shower. You are starting to show signs of a cold. Otherwise all your physical functions appear to be fine. There is one exception; your pulse rate is slightly elevated." [2]

"OK!" she replied, stepping into the stream of water. "Guess the pulse rate is just because I'm looking forward to the prom tonight." Sandra knew that the diagnostic intelligence built into the house AI didn't care if she answered or not, but somehow it seemed to have a personality.

As she adjusted the hot water, enjoying the play of the hot shower on her skin, the communication implant below her ear signaled for attention. [3]

"It's Victoria calling, do you wish to answer?" the implant said through bone conduction.

"Yes, put her on … Hi, Vicky! What's up?"

"Hi, Sandy. So, hey, did you end up renting that Lauren Sigali gown we were talking about?"

"Yeah, and it's awesome. I was playing with it today. It can even generate dynamic patterns," Sandy replied. [4]

"That is so cool. Mine isn't as good as that, but it has great shading and pretty good luminosity. So what color are you going to hue it? I think you should wear blue … it will go with your eyes."

"Yeah. A pale blue … I like that. And I could play a pattern when we start dancing. How about you, Vic?"

"I think I'll hue mine a bright red … make me stand out from the crowd. Maybe I'll flip to green when we dance."

[1] Although a voiceprint is a highly accurate identifier, the touch panel that reads both fingerprints and DNA in the skin is an extra insurance of privacy.

[2] Two approaches could be used for sensing Sandra's physical conditions: Chronic embedded nanosensors that emit signals to be picked up by nearby analytic equipment, or nanosensors that read the presence of substances in the body by contact with the skin or sampling breath.

[3] Communication devices will be built of components assembled at a molecular level and will be able to receive and transmit to local "WiFi" devices in the environment (e.g., house or car). Implants placed on bone tissue near the ear could generate sound that would be heard through bone conduction. The scale of memory devices will permit application specific computers to operate with minimal power, such as that generated from room lights or body heat.

[4] Quantum dots embedded in the fabric of clothing may be controlled to switch colors and create patterns based on electrical impulses from a device sold with the clothing.

"Sounds great, Vic. So did you hear that Munira got an ad gown? It was free."

"Ugh. I just hope it doesn't play one of those tacky logo collages."

"So, what kind of pattern could I make that's personal for this evening?"

They talked for another fifteen minutes before Sandra finally said, "Phone disconnect."

After toweling off and taking the "C' tablet, she turned her attention to makeup. [5] The oil in the cosmetics was broken down so finely that it felt like a second skin. In addition, it acted as a sunblock, which was important here in Nanocity, Arizona. [6]

For the thousandth time Sandra wondered why Nanocity had to be built so far away from any other place. She understood that when the geostationary orbiting space platform had been tethered to the ground, more than half the country thought it would be dangerous. [7] Now, years later, with the "splatform" still up there, and being the key to space exploration and research, nobody worried.

Her dad—who managed the ground station, the tether, and the elevator up to the spatform—had mentioned that there were other political problems to deal with now. In fact, her boyfriend, Lenny had told her that his mother was up at the splatform doing some controversial experiments.

As Sandra took her leisurely time preparing for the evening, Len was finishing his last few laps at the high school track. Light filtered through the translucent concrete dome that covered the stadium, protecting it from the ravages of the sun and, right now, shielding the field from the thunderstorm encircling the valley. [8]

Len felt good as he finished his laps. The leg he had broken in his clumsy attempt at pole vaulting had healed quickly after the doctor injected the nanofiber diamond-coated prosthesis to support the bone until it healed. [9]

Now it was straight to the gym for a shower and then home to get dressed for the prom.

Out of habit, he placed his hand on the wall panel signaling Mother to perform a physical check. The school's AI, nicknamed "Mother" by the kids, recognized him. A few moments after he stepped into the shower, it chirped,

[5] The "C" tablet contains nanobiological machines that attract and attach to viruses, preventing them from infiltrating cells.

[6] Nanobots are used to break the oil down into smaller molecular clusters than can be done with refining methods alone.

[7] The tether, made of carbon nanotubes weaved into a huge cable, reaches from the ground station to the splatform about 36,000 kilometers above the earth. Fibers of the cable are electrically conductive, permitting transmission of power to elevator motors, which lift items into space much more economically than rockets could.

[8] The dome is made of sheets of concrete layered internally with carbon nanotubes and light conductive fiber so that it appears translucent.

[9] Diamondoid structures are a derivative of the carbon-based nanotubes, but are anatomically neutral, and thus cannot harbor infection.

"Leonard Gonzales, all systems are go. You have not ingested any prohibited substances." The same message was recorded in the coach's log files. Any time the coach wanted to, he could get a view of the condition of every player from readings of their chronic sensor implants.

Len grinned, … "all systems are go," he laughed. Mother was an old AI system still using outdated phrases.

He dressed quickly, went out to his car in the parking lot, and pressed his thumb against the keyspot on the door to unlock it. [10] Len was proud of his first car. Like his dad's, it had a lightweight nanotube reinforced fiber body that was the same color all the way through, so even deep scratches didn't show. The main difference was that his car was electric and his Dad's car, built for longer distance driving, was hydrogen powered. The hydrogen, of course, was refilled at the solar fuel station on the highway. [11] Len's car captured some electricity from solar conversion and braking, and he fully recharged it by plugging into the grid, usually at home.

As he put his hands on the steering wheel, there was a slight pause as the car checked his breath (to make sure that he hadn't had anything that would impair his driving) and his prints, again, to make sure that he was the registered owner or a designated alternate driver. In less than a second, the green light came on and he shifted into "drive."

Before he pulled out of the school lot, his communication implant signaled a call from his mother, who was taking the elevator home from work. Len's mom had been up at the spaltform's isolation lab supervising the start of a new series of experimental nanocapsules for prescription drug delivery via the blood to specific cell types in the body. [12]

"Hello, Madre Mia! What's up?" Len answered the call.

"I can't seem to reach your father, Len, and I wanted him to know that the storm may slow us down a bit. You know … the risk of electrical interference."

"Mom, I don't understand why the isolation lab has to be on the splatform. I think you have the longest commute of anyone I know." [13]

"Maybe you're right about the commute, Len. But tell your father that I'll be delayed a bit. He should go ahead with dinner without me."

[10] The keyspot is similar to the wall panel identifier in note 2.

[11] Electricity from the national (or international) power grid is used locally at the filling station to power the nanomachine chemical conversion of water to hydrogen and oxygen. Burning the hydrogen in the car's engine results in a nonpolluting exhaust (the only exhaust product is water).

[12] Nano encapsulation technologies (using, for example, nanotubes and fullerines) can be treated to bond with cells of specific organs of the body and deliver their load of medication directly rather than spreading it throughout the body. (Kidney medication to kidney cells, etc.)

[13] The splatform is far above Earth's atmosphere, where there are few air particles to provide friction. With less friction, the electrically powered elevator running on the tether can achieve speeds that would not be possible within Earth's atmosphere, making such a commute possible on a daily basis.

"OK, but really, Mom, you don't need a weightless environment for the lab work. Everyone knows that nano particles are influenced more by inertia, friction, and Brownian motion than by gravity."

"That's true, Len. The reason for the isolation lab being on the splatform is political, not scientific. You know, for example, that nanotubes and buckyballs can be toxic if you're overexposed. Well, a lot of people are worried about the possible toxic effects of other nanoscale particles. Enough of them fear some strange new 'world plague' that they have passed laws prohibiting some research from being done on Earth, so we do it in space. If something goes wrong, we abandon the lab, thrust it, and have it burn up before it hits the Pacific."

"But why do you have to be there?" Len asked. "I thought the lab was automated."

"Well, Len, one thing that our best AI can't do is adapt to unforeseen circumstances … there's always a need for the personal touch."

"Yeah, I guess … but it's still a long commute." Len grumbled.

"Sorry, kiddo. Have a good time tonight and I'll see you in the morning."

Len signed off and signaled his implant to stream music from his favorite narrowband.

After driving home, he pulled into the garage and the charger moved out to plug into the car. The car was covered with solar converter paint that recharged the battery from sunlight, but this wasn't always enough to keep the car fully charged [14]. Electricity generated by solar converters placed in large areas throughout the world, such as these Arizona deserts, was fed into the national grid.

He left a message for his father and started to prepare for the prom. As he laid out his clothes on the bed, his stomach growled, so he went to the kitchen for a snack. It might be late by the time the food was served at the prom, and a small sandwich couldn't hurt. Afterwards, he took a mouthful of Nanodent. The nanomachines in the mouthwash recognized particles of food, plaque, and tartar and lifted them from the teeth and gums to be rinsed away. [15]

Within an hour, he was dressed and on his way across town to pick up Sandra.

At Sandra's house, Ms. Houston met him at the door. "Sandra will be ready

[14] The "paint' is composed of a medium in which molecular solar energy conversion cells are implanted. In the future, nano solar cells that could be rolled out, ink-jet printed, or painted onto surfaces.

[15] Being suspended in liquid and able to swim about, nanobots could reach surfaces beyond reach of toothbrush bristles or the fibers of floss. After a few minutes in the body, they would fall apart into harmless fiber. With such easy daily dental care from an early age, tooth decay and gum disease may never arise.

in a few minutes. You know that girls going to a prom can't be ready on time. It would violate some rule of the universe," she laughed. "Have a seat, Lenny. Want something to drink while you wait?"

"That would be macro, thanks. Maybe some juice?" Len sat in the living room feeling a little awkward with his formal clothes and corsage box in hand.

Ms. Houston brought in some grape juice and handed it to Len. A bit nervous about these relatively rare meetings with Sandra's mother, he spilled some of the juice on his white shirt.

"Oh, sh…!" He stopped what he was about to say.

Ms. Houston laughed reassuringly. "No worries. Here, let me get a damp cloth, Lenny. These rented formal clothes reject anything that is non-fabric. It'll just wipe off." [16] She led Len to the kitchen and wiped off the stain.

[16] Nanofibers in cloth will not allow dirt or other objects to adhere. These "nanowhiskers" act like peach fuzz and create a cushion of air around the fabric so that liquids bead up and roll off.

"Thanks, Ms. Houston." Len grinned. "I guess I'd better just sit down and wait."

Finally, after a seemingly interminable dozen minutes, Sandra walked into the room in glimmering pale blue gown and asked breezily, "Have I kept you waiting, Len?"

Len grimaced and Sandra laughed.

He handed her the corsage box and she beamed when she opened it.

"Goodnight, Mom," Sandra called out.

"Goodnight, Ms. Houston," Len echoed.

"Don't forget to send me a few pictures of the prom." Ms. Houston waved as they walked away.

"I'll be too busy, Mom," Sandra replied. But they'll be taking class pics at the entrance. They'll go right onto the class net."

As they walked out to the car, Sandra looked at Len and touched his shoulder, turning him around to face her. With a smile, she grabbed his hand and placed it on her shoulder. He leaned in for a kiss.

"Hold on, sport, I'm just recording your hand's temperature gradient. I already recorded mine. My gown will use them to create a pattern of color gradients. You'll see when we dance." Sandy worked the gown's controller. [17]

[17] See note 4. Quantum dots can be tuned to emit different wavelengths of light. These small nano-scale crystalline structures will also be used as fluorescent labels in biological imaging and drug discovery research.

"Well I'm glad I'm good for something," he said.

"There's always a need for the personal touch," she quipped.

"Seems I've heard that somewhere else today," Len mumbled to himself.

Related Reading

(Accessed August 2005.)

- Top 10 future applications of nanotechnology
  http://www.utoronto.ca/jcb/home/documents/PLoS_nanotech.pdf&e=10431
- Nanotechnology predictions
  http://www.nanotech-now.com/predictions.htm
- Space elevator made with carbon nanotubes
  http://www.space.com/businesstechnology/technology/space_elevator_020327-1.html
- Dreaming about nano health care
  http://wired-vig.wired.com/news/technology/0,1282,40166,00.html?tw=wn_story_related
- Nanodentistry
  http://www.rfreitas.com/Nano/Nanodentistry.htm
- Quantum dot pigments and infrared paints
  http://www.evidenttech.com/applications/quantum-dot-pigments.php
- Meeting energy needs with nanotechnology
  http://www.foresight.org/challenges/energy001.html
- Nanotechnology in construction
  http://www.aggregateresearch.com/article.asp?id=6279
- Nanotechnology in clothing
  http://www.sciencentral.com/articles/view.php3?article_id=218391840&cat=3_5

Name_________________________________ Date_____________________ Period ______

The Personal Touch: Student Worksheet

You will read a story that describes how nanotechnology might impact daily life in 2045. The story is fictional, but is based on current or proposed research, and in some cases, already-existing technology.

1. BEFORE you read the story, predict, and write below, TWO ways that you think that nanoscience or nanotechnology might affect your life in the future.

Prediction 1:

Prediction 2:

2. READ THE STORY SILENTLY TO YOURSELF.

3. Summarize, and write below, FOUR applications of nanotechnology mentioned in the story.

Application 1:

Application 2:

Application 3:

Application 4:

4. What application mentioned in the story do you think is MOST believable, and why?

5. What application mentioned in the story do you think is LEAST believable, and why?

6. Write below at least TWO science-related questions that you have about this story.

Question 1:

Question 2:

Lesson 2:
Scale of Objects

Teacher Materials

Contents

Scale of Objects: Teacher Lesson Plan

Orientation

This lesson helps students think about the enormous scale differences in our universe. There are three classroom activities that you can choose between and combine.

- The Student Reading on Visualizing the Nanoscale reviews common size units and provides several examples to help students imagine the nanoscale.
- The Number Line/Card Sort Activity has students place objects along a scale and reflect on the size of common objects in relation to each other.
- The Scale of Small Objects Activity/Worksheet has students identify the size scale of objects with less focus on their relation to each other.
- The Cutting It Down Activity has students cut a strip of paper in half as many times as possible and focuses on tools and their precision at different scales.
- The Scale of Small Objects Quiz tests the absolute and relative size of objects.

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?

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.

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.

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.

Related Standards

- NSES Science as Inquiry: 12ASI2.3
- AAAS Benchmarks: 11D Scale #1

Day	Activity	Time	Materials
Prior to this lesson	*Homework*: Reading & Worksheet: Visualizing the Nanoscale	*30 min*	Photocopies of Visualizing the Nanoscale: Student Reading
Day 1 (40 min)	Use Visualizing the Nanoscale: Student Reading as a basis for class discussion and student questions. Use the Scale Diagram: Dominant Objects, Tools, Models, and Forces at Various Different Scales as a reference.	10 min	Students will refer to the Scale Diagram handout; photocopy it if not previously handed out.
	Number Line/Card Sort Activity or	20 min	Photocopies of Number Line/Card Sort Activity: Student Instructions & Worksheet A set of cards (objects and units) for each small group of students (consider printing cards on card stock for reuse)
	Cutting it Down Activity or		Photocopies of Cutting It Down Activity: Student Instructions & Worksheet Strips of Paper Scissors
	Scale of Objects Activity		Photocopies of Scale of Objects Activity: Student Instructions & Worksheet
	Return to whole class discussion for questions and comments	5 min	
	Scale of Small Objects: Student Quiz	5 min	Photocopy Scale of Small Objects: Student Quiz Teacher Key for correcting Student Quiz

Number Line/Card Sort Activity: Teacher Instructions & Key

Overview

In this activity, your students will explore their perception of the size of different objects. Have your students form into pairs or small groups, and give each group the Number Line/Card Sort Activity: Student Instructions & Worksheet handout and two sets of cards: one with objects on them and one with units on them. Their task is to create a number line and place the cards at the appropriate places on the number line.

You may also want to discuss with your students why we are using powers of 10 for the units in this exercise instead of using a "regular" linear scale (e.g., a meter stick). Here are some questions and issues you may want to bring up:

The number line units are powers of 10; that is, they are a base 10 logarithmic scale. Why don't we just use a linear scale, like a meter stick? Using a linear scale, we could easily mark off 1 meter, 1 cm, and 1 mm. But it's hard to mark (or see) smaller than that. Plus, most of the cards (for small objects) would pile up on top of each other!

Instead, we'd like to spread our cards out to clearly see which objects are bigger or smaller than others. We can do this if we use a logarithmic scale. The word logarithm is a synonym for the words "exponent" or "power." Powers of 10 use a base 10 logarithm scale. In base 10, $Log_{10}(10^{-10}) = -10$. So, each card unit represents an exponent (-10, -9, -8 … -1, 0) of 10. These are integers that are equidistant from each other.

Materials

- Cards for the objects
- Cards for the units, in powers of 10 meters

Instructions

On a surface like a lab table, order the cards for powers of 10 in a vertical column, with the largest at the top and the smallest at the bottom. Space the cards equidistant from each other, leaving a gap between the cards for 10^{-10} and 10^{-15}. This is your number line.

Next, place each object next to the closest power of 10 in the number line that represents the size of that object in meters. Some objects may lie between two powers of 10.

When you are done placing all of the cards, record your results in the table on the next page and answer the questions that follow.

Card choices adapted from Tretter, T. R., Jones, M. G., Andre, T., Negishi, A., & Minogue, J. (2005). Conceptual Boundaries and Distances: Students' and Experts' Concepts of the Scale of Scientific Phenomena. *Journal of Research in Science Teaching.*

Size (meters)	Objects
10^{0}	21. height of a typical NBA basketball player 4. height of a typical 5-year-old child
10^{-1}	20. length of a phone book 16. length of a business envelope 9. width of an electrical outlet cover
10^{-2}	17. diameter of a quarter 7. width of a typical wedding ring 14. length of an apple seed
10^{-3}	1. thickness of a penny 23. thickness of a staple 11. thickness of sewing thread
10^{-4}	6. length of a dust mite 8. length of an amoeba 18. length of a human muscle cell
10^{-5}	3. diameter of a red blood cell
10^{-6}	13. width of a bacterium
10^{-7}	24. wavelength of visible light (between 10^{-7} and 10^{-6}) 15. diameter of a virus
10^{-8}	10. diameter of a ribosome 5. width of a proteinase enzyme 19. diameter of a carbon nanotube
10^{-9}	12. width of a water molecule
10^{-10}	22. diameter of a nitrogen atom
10^{-15}	2. nucleus of an oxygen atom

Questions

1. Which items were the hardest for you to estimate size for? Why?

   Students will probably list small objects they know the least about. For example, if they haven't taken biology, they may list virus, ribosome, etc.

2. Why are we using powers of 10 for the number line instead of a regular linear scale (like a meter stick)?

   With a power of 10 scale, we can spread the unit markers out evenly so that we can clearly place and see all of the cards. If we used a linear scale, most of the cards would pile up on top of each other. And we can't easily make marks much smaller than a millimeter anyway, so we couldn't make or see our scale if it were linear!

Cutting it Down Activity: Teacher Instructions & Key

Purpose

The purpose of this activity is to help students understand the smallness of the nanoscale, appreciate the impossibility of creating nanoscale materials with macro scale objects, and to understand the invisibility of the nanoscale to the unaided eye. [1]

Materials

For each group of students, provide

- Scissors
- A strip of paper (cut a narrow strip from an 8.5 x 11 inch sheet of paper, approximately 8.5 inches long by 1/4 inch wide, or 216 mm x 5 mm)
- Pen or pencil
- Ruler
- Calculator

Classroom Activity

Show the students the strip of paper and tell them what its dimensions are. Explain to them that the challenge is to cut the piece of paper in half repeatedly in order to make it 10 nm long.

Have the students get in pairs and give each pair the ruler, calculator, scissors, pen/pencil (if necessary), strip of paper, and the Cutting It Down Activity: Student Worksheet. Remind them to answer the first two questions on the worksheet before they begin cutting. Tell them they have 10 minutes to complete the activity.

As a variation, you could have students do the exercise more than once with different kinds of scissors or other cutting tools to demonstrate the power and limitations of tools.

Discussion

When the students have finished the activity, discuss the questions on their worksheets. Focus on the following questions first:

- Were their predictions to the first two questions accurate?
- How many times were they able to cut the paper?

After discussing these questions, focus on the remaining questions on their worksheets. As a closing point, emphasize that the demonstration shows how small nano really is and how inadequate macro scale tools (like the scissors), are in dealing with the nanoscale.

- If you have had students use different kinds of scissors or other cutting tools, you can also discuss the relationship between form and size of the tool and its precisions and usefulness at a certain size scale. For example, an x-acto blade can be used to make much finer cuts than a pair of scissors, although both are too big to be useful at the nanoscale.

[1] Adapted from http://mrsec.wisc.edu/Edetc/IPSE04/educators/activities/cuttingNano.html

Student Instructions

How many times do you think you would need to cut a strip of paper in half in order to make it between zero and 10 nanometers long? In this activity, you'll cut a strip of paper in half as many times as you can, and think about the process.

BEFORE you begin cutting the strip of paper, answer the following questions (take a guess):

1. How many times do you need to cut the paper in half to obtain a 10 nanometer long piece?

Answers will vary, since this is a prediction. Should be a fairly large integer value.

2. How many times do you think you can cut the paper before it becomes impossible to cut?

Answers will vary, since this is a prediction. Should be an integer value that is smaller than the answer to question 1.

Now cut the strip of paper in half as many times as you can. Remember to keep track of how many cuts you make.

AFTER completing the activity, answer the following questions.

3. Were your predictions to the above two questions accurate?

Answers will vary, but should indicate if their predictions matched their results.

4. How many times were you able to cut the paper?

Answers will vary, but should be an integer number, likely in the range of 6-8 cuts.

5. How close was your smallest piece to the nanoscale?

Very far. By cutting with a typical pair of scissors, you probably can get down to about the 1 mm range, which is 10^{-3} meters. The nanoscale range is 10^{-7} to 10^{-9} meters, or 4 to 6 powers of ten smaller.

6. Why did you have to stop cutting?

Couldn't position the paper on the scissors; the scissors were too big relative to the paper to cut any more, etc.

7. Can macroscale objects, like scissors, be used at the nanoscale?

No.

8. Can you think of a way to cut the paper any smaller?

Answers might include using a microscope, smaller scissors, or finer cutting tools.

Scale of Objects Activity: Teacher Key

In this activity, you will explore your perceptions different sizes. For each of the following items, indicate its size by placing an “X” the box that is closest to your guess.

Key:

A. Less than 1 nanometer (1 nm) [Less than 10^{-9} meter]
B. Between 1 nanometer (nm) and 100 nanometers (100 nm) [Between 10^{-9} and 10^{-7} meters]
C. Between 100 nanometers (100 nm) and 1 micrometer (1 µm) [Between 10^{-7} and 10^{-6} meters]
D. Between 1 micrometer (1 µm) and 1 millimeter (1 mm) [Between 10^{-6} and 10^{-3} meters]
E. Between 1 millimeter (1mm) and 1 centimeter (1 cm) [Between 10^{-3} and 10^{-2} meters]
F. Between 1 centimeter (1 cm) and 1 meter (m) [Between 10^{-2} and 10^{0} meters]
G. Between 1 meter and 10 meters [Between 10^{0} and 10^{1} meters]
H. More than 10 meters [More than 10^{1} meters]

	Less than 1 nm	**1 nm to 100 nm**	**100 nm to 1 µm**	**1 µm to 1 mm**	**1 mm to 1 cm**	**1 cm to 1 m**	**1 m to 10 m**	**More than 10 m**
Object	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
1. Width of a human hair				x				
2. Length of a football field								x
3. Diameter of a virus		x						
4. Diameter of a hollow ball made of 60 carbon atoms (a “buckyball”)		x						
5. Diameter of a molecule of hemoglobin		x						
6. Diameter of a hydrogen atom	x							
7. Length of a molecule of sucrose		x						
8. Diameter of a human blood cell				x				
9. Length of an ant					x			
10. Height of an elephant							x	
11. Diameter of a ribosome		x						
12. Wavelength of visible light			x					
13. Height of a typical adult person							x	
14. Length of a new pencil						x		
15. Length of a school bus								x
16. Diameter of the nucleus of a carbon atom	x							
17. Length of a grain of white rice					x			
18. Length of a postage stamp						x		
19. Length of a typical science textbook						x		
20. Length of an adult’s little finger						x		

Adapted from Tretter, T. R., Jones, M. G., Andre, T., Negishi, A., & Minogue, J. (2005). Conceptual Boundaries and Distances: Students’ and Experts’ Concepts of the Scale of Scientific Phenomena. *Journal of Research in Science Teaching*.

Scale of Small Objects: Teacher Key

1. Indicate the size of each object below by placing an "X" the appropriate box.

Key:

A. Less than 1 nanometer (1nm) [Less than 10^{-9} meter]
B. Between 1 nanometer (nm) and 100 nanometers (100 nm) [Between 10^{-9} and 10^{-7} meters]
C. Between 100 nanometers (100 nm) and 1 micrometer (1 µm) [Between 10^{-7} and 10^{-6} meters]
D. Between 1 micrometer (1 µm) and 1 millimeter (1 mm) [Between 10^{-6} and 10^{-3} meters]
E. Between 1 millimeter (1 mm) and 1 centimeter (1 cm) [Between 10^{-3} and 10^{-2} meters]

	Less than 1 nm	**1 nm to 100 nm**	**100 nm to 1 µm**	**1 µm to 1 mm**	**1 mm to 1 cm**
Object	**A**	**B**	**C**	**D**	**E**
1. Width of a human hair				**x**	
2. Diameter of a hollow ball made of 60 carbon atoms (a "buckyball")		**x**			
3. Diameter of a hydrogen atom	**x**				
4. Diameter of a human blood cell				**x**	
5. Wavelength of visible light			**x**		

2. Order the following items in order of their size, from smallest to largest.

a. Width of a water molecule
d. Diameter of a gold atom
c. Thickness of a staple
d. Diameter of a virus
e. Length of an amoeba
f. Diameter of a carbon nanotube

Smallest:	___d_____
	___a_____
	___f_____
	___d_____
	___e_____
Largest:	___c_____

Lesson 2:
Scale of Objects

Student Materials

Contents

Visualizing the Nanoscale: Student Reading

How Small is a Nanometer?

The meter (m) is the basic unit of length in the metric system, and a nanometer is one billionth of a meter. It's easy for us to visualize a meter; that's about 3 feet. But a billionth of that? It's a scale so different from what we're used to that it's difficult to imagine.

What Are Common Size Units, and Where is the Nanoscale Relative to Them?

Table 1 below shows some common size units and their various notations (exponential, number, English) and examples of objects that illustrate about how big each unit is.

Table 1. Common size units and examples.

Unit	Magnitude as an exponent (m)	Magnitude as a number (m)	English Expression	About how big?
Meter	10^{0}	1	One	A bit bigger than a yardstick
Centimeter	10^{-2}	0.01	One Hundredth	Width of a fingernail
Millimeter	10^{-3}	0.001	One Thousandth	Thickness of a dime
Micrometer	10^{-6}	0.000001	One Millionth	A single cell
Nanometer	10^{-9}	0.000000001	One Billionth	10 hydrogen atoms lined up
Angstrom	10^{-10}	0.0000000001		A large atom

Nanoscience is the study and development of materials and structures in the range of 1 nm (10^{-9} m) to 100 nanometers ($100 \times 10^{-9} = 10^{-7}$ m) and the unique properties that arise at that scale. That is small! At the nanoscale, we are manipulating objects that are more than one-millionth the size of the period at the end of this sentence.

What if We Measured the Size of Various Objects in Terms of Nanometers?

A typical atom is anywhere from 0.1 to 0.5 nanometers in diameter. **DNA** molecules are about 2.5 nanometers wide. Most **proteins** are about 10 nanometers wide, and a typical **virus** is about 100 nanometers wide. A **bacterium** is about 1000 nanometers. Human cells, such as red blood cells, are about 10,000 nanometers across. At 100,000 nanometers, the width of a human hair seems gigantic. The head of a pin is about a million nanometers wide. An adult man who is 2 meters tall (6 feet 5 inches) is about 2 billion nanometers tall!

So is That What Nanoscience is All About—Smallness?

No, smallness alone doesn't account for all the interest in the nanoscale. Nanoscale structures push the envelope of physics, moving into the strange world of **quantum mechanics**. For nanoparticles, gravity hardly matters due to their small mass. However, the **Brownian motion** of these particles now becomes important. Nanosized particles of any given substance exhibit different properties and behaviors than larger particles of the same substance.

For now, though, we'll focus just on the smallness of nanoscale, and ways to visualize how extremely tiny the nanoscale is.

How Can We Imagine the Nanoscale?

Another way to imagine the nanoscale is to think in terms of relative sizes. Consider yourself with respect to the size of an ant (3-5 millimeters). An ant is roughly 1000 times smaller than you are. Now think of an ant with respect to the size of an **amoeba** (about 1 micron). An amoeba is about 1000 times smaller than an ant. Now, consider that a nanometer is roughly 1000 time smaller than an amoeba! You would have to shrink yourself down by a factor of 1000 three times in a row in order to get down too the level of the nanoscale.

Imagine Zooming In on Your Hand

Let's try to conceptualize the nanoscale yet another way. Look at your hand. Let's zoom into your hand by a factor of ten, several times in a row (see Figure 1, below).

In frame 1, at the 10 centimeter scale (10^{-1} m), we can see fingers and skin clearly. As we zoom in by a factor of ten to the 1 centimeter scale (10^{-2} m), we can begin to see the structure of skin (frame 2). If we move in another factor of ten to the 1 millimeter scale (10^{-3} m), we can see cracks in the skin clearly (frame 3). Moving in again by another factor of ten to the 100 micron level (10^{-4} m), the cracks look like deep crevices (frame 4). Zooming in again, to 10 microns (10^{-5} m), we can see an individual cell (frame 5). At the next level, 1 micron (10^{-6} m) we can see the membrane of the cell and some of the features that exist on it (frame 6). Moving in another factor of ten to the 100 nm scale (10^{-7} m), we begin to see the individual DNA strands that exist within nucleus of the cell. This is the scale at which computer technology is currently being fabricated (frame 7). Zooming in again to the 10 nm length scale (10^{-8} m), we see the double helix that make up DNA. Finally, zooming in one last time to the 1 nanometer scale (10^{-9} m), we can see the see individual atoms that make up DNA strands!

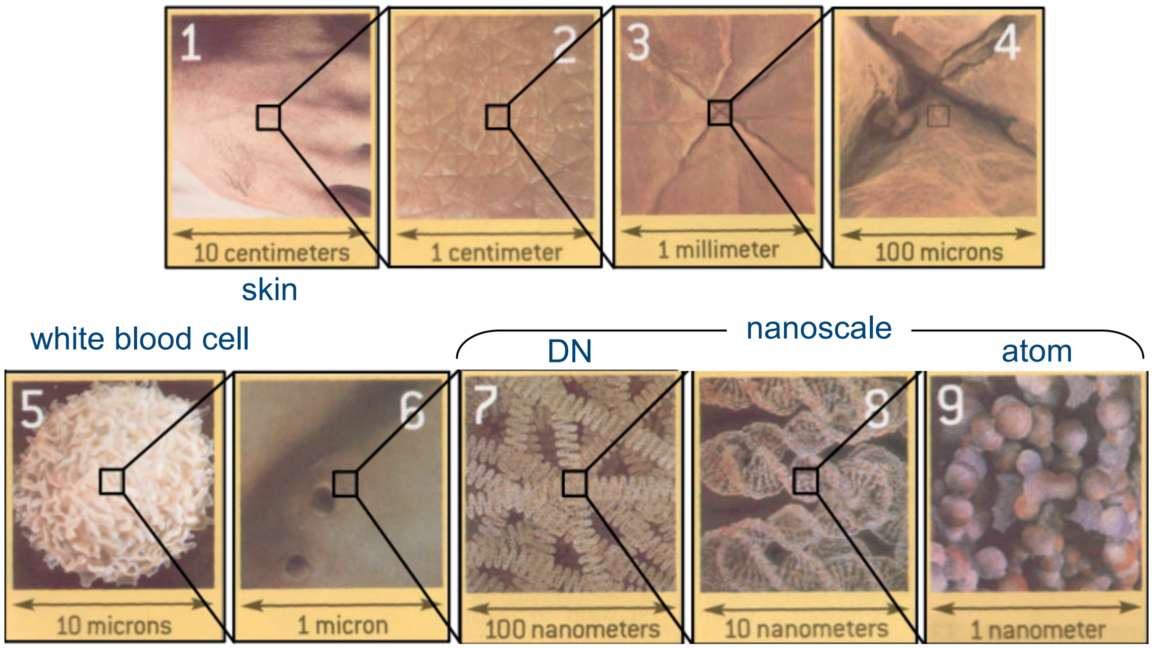


Figure 1. Zooming in on your hand by powers of 10 [1].

What is This Powers of 10 Stuff?

In the above example, each picture is an image of something that is 10 times bigger or smaller than the one preceding or following it. The number below each image is the scale of the object in the picture. In the text above, the scale is also written in powers of ten, or exponential notation (e.g., 10^{-2}) where the scale is mentioned. Since the ranges of magnitudes in our universe are immense, exponential notation is a convenient way to write such very large or very small numbers.

The Molecular Expressions Web site offers a nice interactive visualization of magnitudes in our universe; see http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10/. The interactive Java applet on this site moves through space in successive orders of magnitude from the Milky Way galaxy (10^{21} m). our solar system (10^{13} m). towards the Earth (10^{18} m), to a city (10^{4} m), a tree (10^{1} m), a leaf (10^{-1} m), cells (10^{-5} m), strands if DNA (10^{-7} m), an atom (10^{-10} m), and eventually **quarks** (10^{-16} m). Check it out!

Another Shrinking Exercise

Recall that we said that you'd have to shrink yourself down by a factor of 1000 three times in a row to get to the nanoscale. Let's try that! [2]

Imagine you are sitting at your desk with the following items: A box, a baseball, a marble, and a grain of salt, as show below. These items represent a length spread of 3 orders of magnitude. Each item is 10 times longer than the item to its left. The box is 1000 times longer than the grain of salt. These objects are in the realm of what is often referred to as the macroscale.

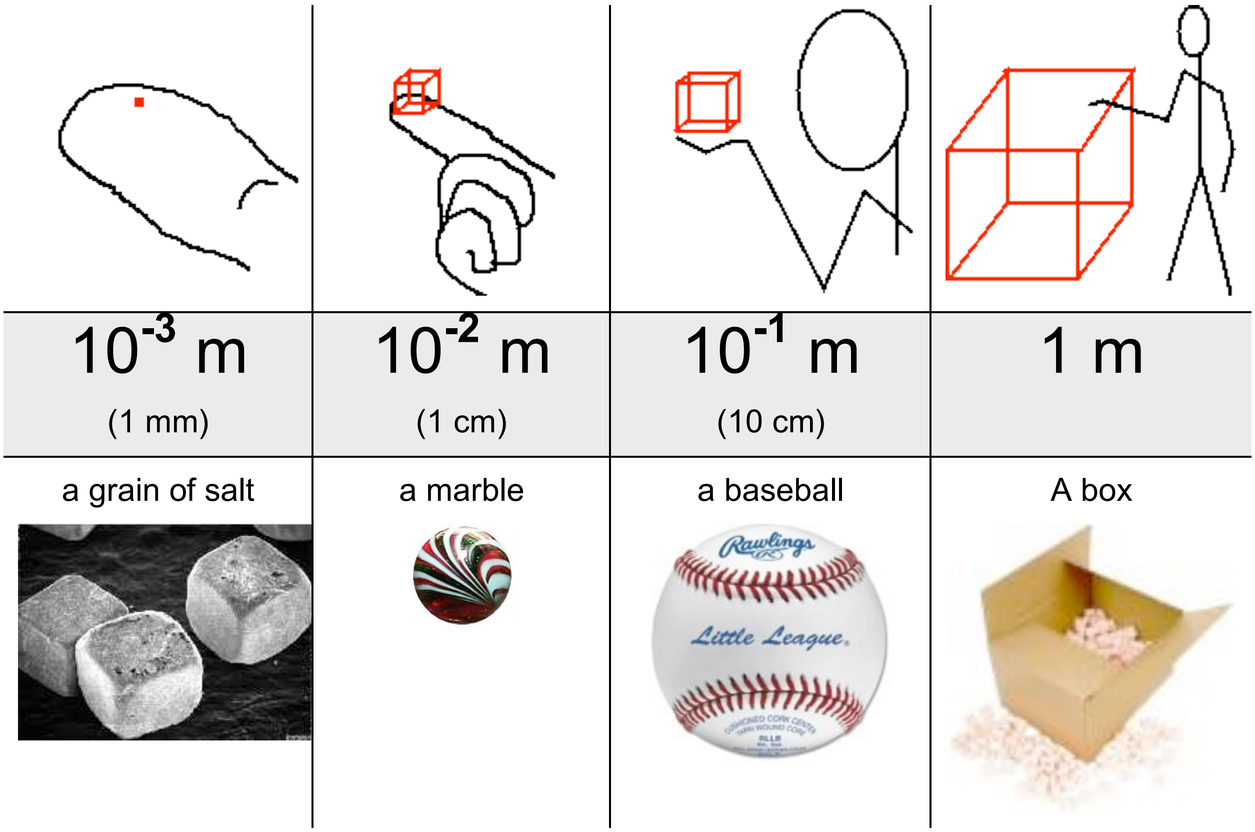


Figure 2. The macroscale.

What if we zoomed in 1000 times, so that the grain of salt was as big as the box?

- We could stand next to the grain of salt, and use it as a bed or a desk.
- Dust mites would look like hand-sized turtles, and your hair would look like giant ropes.
- Blood cells would be little red and white marbles.
- Bacteria on your skin would look like little grains of sand.

These objects, measured in microns, are in the realm of what is referred to as the microscale.

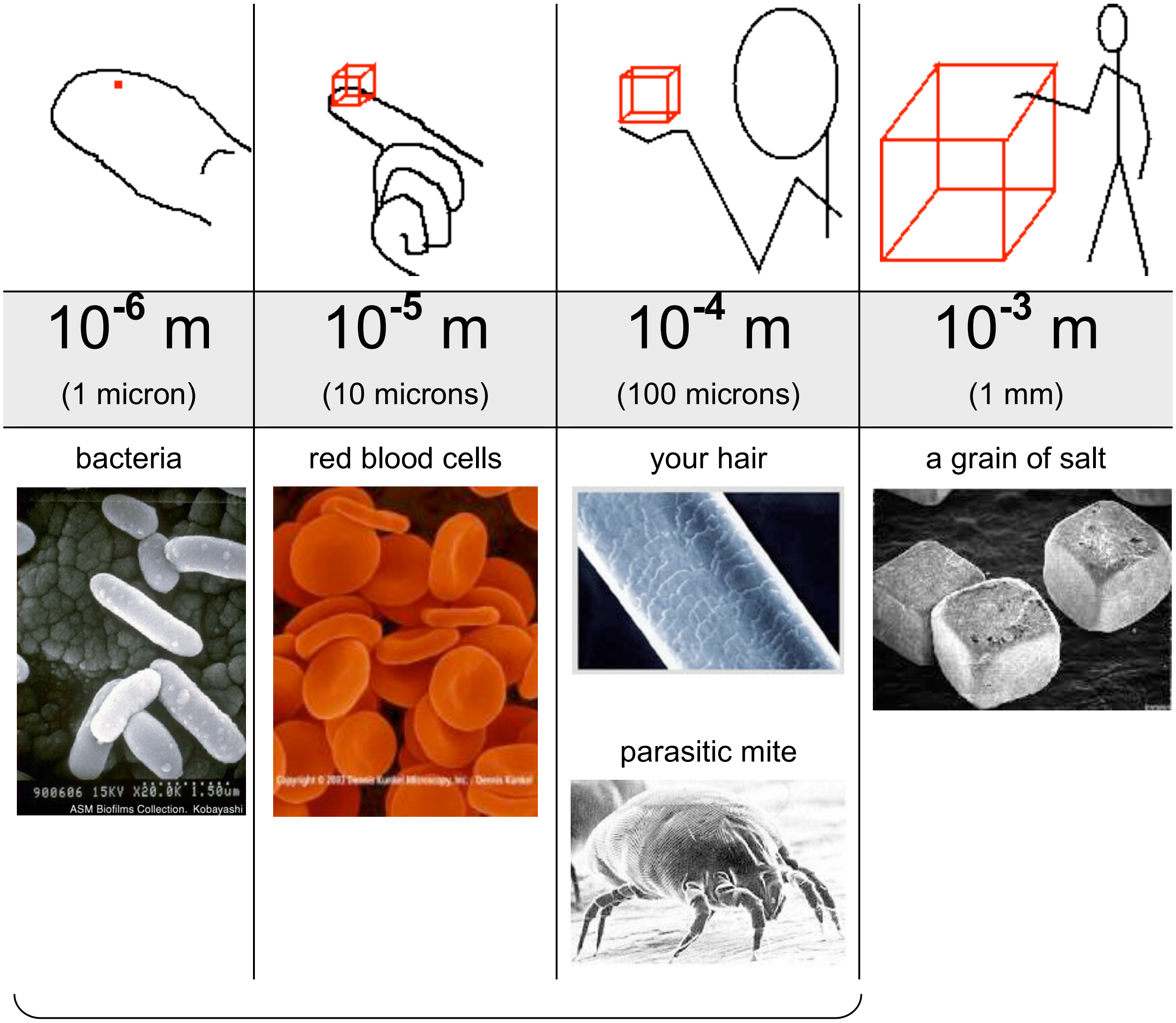


Figure 3. The microscale.

What if we zoomed in 1000 times again, so that the bacteria were as big as the box?

- We could sit on the bacteria like easy chairs.
- We could use viruses for batting practice.
- We could play marbles with proteins and large molecules.
- Atoms and small molecules would look like little grains of sand.

These objects, measured in nanometers, are in the realm of what is referred to as the nanoscale.

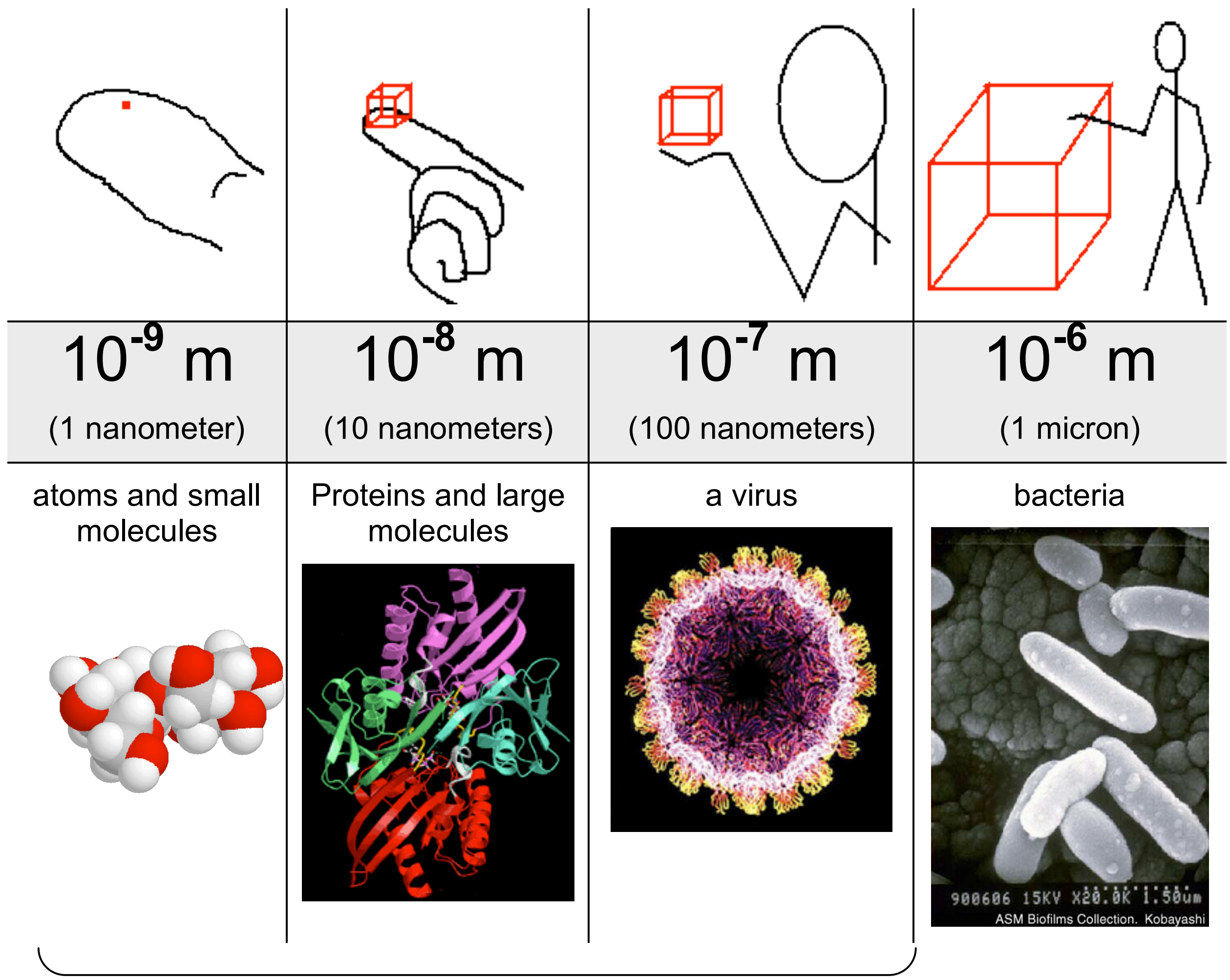


Figure 4. The nanoscale.

Summary

Although many sizes in the universe—including the nanoscale—are hard for us to comprehend because they are far removed from our experience, we can represent such sizes in mathematical notation and through relationships and analogies. Hopefully the examples and analogies used here help you better comprehend the size and scale of the nanoworld.

References

(Accessed August 2005.)

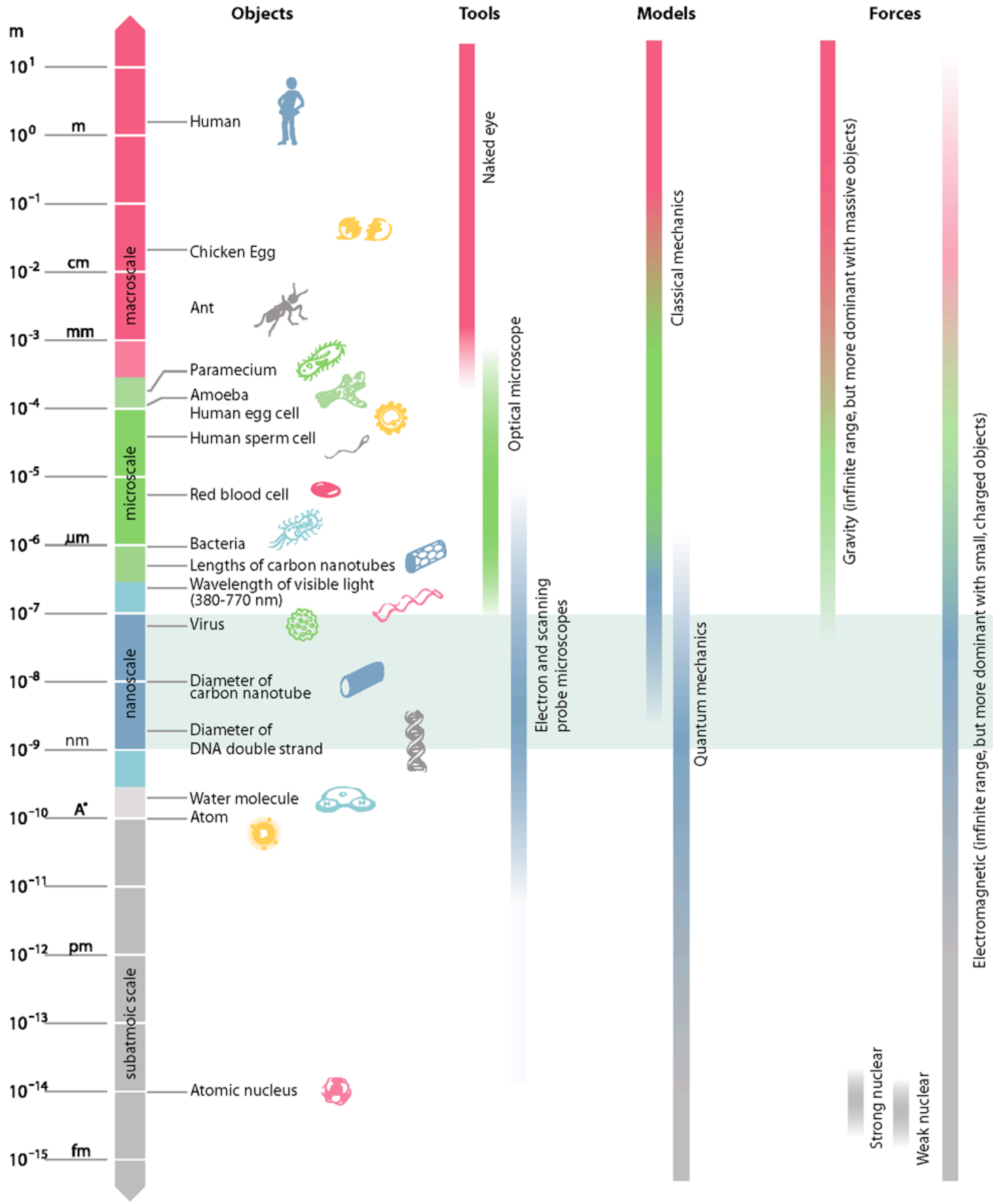
[1] From M. Hersam's Introduction to Nanometer Scale Science & Technology at http://www.materialsworld.net/nclt/docs/Introduction%20to%20Nano%201-18-05.pdf

[2] Adapted from "A view from the back of the envelope" at http://www.vendian.org/envelope/

Glossary

Term	Definition
amoeba	A single-celled organism with a nucleus, found in fresh or salt water environments.
bacterium	A structurally simple single cell with no nucleus. Bacteria occur naturally almost everywhere on Earth including soil, skin, on plants and many foods.
Brownian motion	The random motion of microscopic particles suspended in a liquid or gas, caused by collision with surrounding molecules.
DNA	The genetic material of almost every organism. It is a long, double-stranded, helical molecule that contains genetic instructions for growth, development, and replication.
protein	An organic compound whose structure is dictated by DNA. Proteins perform a wide variety of functions in the cell including serving as enzymes, structural components, or signaling molecules.
quantum mechanics	A scientific model useful for describing the behavior of very small particles (such as atoms and small molecules). Motion is described by probabilistic wave functions and energy can only exist in discrete (quantized) amounts.
quark	The basic building block of matter. Quarks combine with gluons to make the protons and neutrons that make up every atom in the universe.
virus	A structure containing proteins and nucleic acid. Viruses can infect cells and reproduce only by using their cellular machinery.
wave function	A mathematical equation used in quantum mechanics to describe the wave characteristics of a particle. The value of the wave function of a particle at a given point of space and time is related to the likelihood of the particle's being there at the time.

Scale Diagram: Dominant Objects, Tools, Models, and Forces at Various Different Scales



Name_________________________________ Date_____________________ Period ______

Number Line/Card Sort Activity: Student Instructions & Worksheet

In this activity, you will explore your perception of the size of different items. Your task is to create a "powers of 10" number line and place items appropriately on the number line.

Materials

- Cards for the objects
- Cards for the units, in powers of 10 meters

Instructions

On a surface like a lab table, order the cards for powers of 10 in a vertical column, with the largest at the top and the smallest at the bottom. Space the cards equidistant from each other, leaving a gap between the cards for 10^{-10} and 10^{-15}. This is your number line.

Next, place each object next to the closest power of 10 in the number line that represents the size of that object in meters. Some objects may lie between two powers of 10.

When you are done placing all of the cards, record your results in the table on the next page and answer the questions that follow.

Size (meters)	Objects
10^{0}	
10^{-1}	
10^{-2}	
10^{-3}	
10^{-4}	
10^{-5}	
10^{-6}	
10^{-7}	
10^{-8}	
10^{-9}	
10^{-10}	
(large gap)	
10^{-15}	

1. Which objects were the hardest for you to estimate size for? Why?

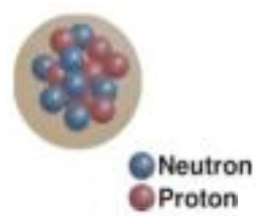
2. Why are we using powers of 10 for the number line instead of a regular linear scale (like a meter stick)?

Cards for Number Line Activity: Objects

(Printing on card stock paper is recommended; then cut to separate.)

1. thickness of a penny

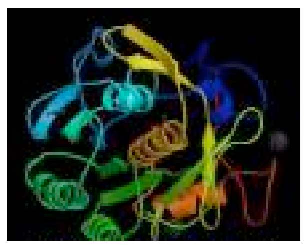
2. nucleus of an oxygen atom



3. diameter of a red blood cell

4. height of a typical 5-year-old child

5. width of a proteinase enzyme



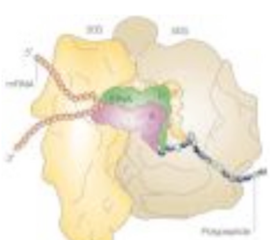
6. length of a dust mite

7. width of a typical wedding ring

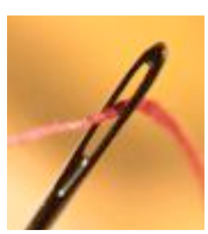
8. length of an amoeba

9. width of an electrical outlet cover

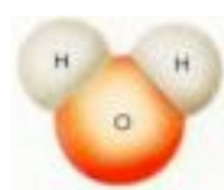
10. diameter of a ribosome



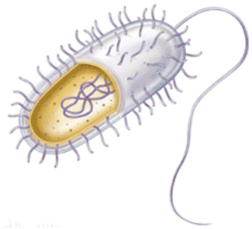
11. thickness of sewing thread



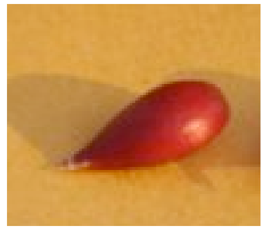
12. width of a water molecule



13. width of a bacterium



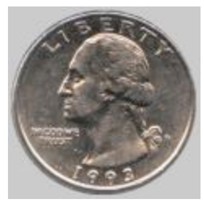
14. length of an apple seed



15. diameter of a virus

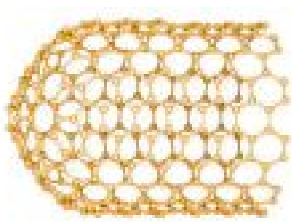
16. length of a business envelope

17. diameter of a quarter

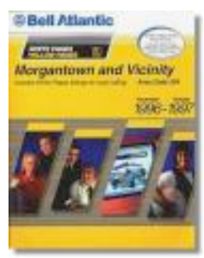


18. length of a human muscle cell

19. diameter of a carbon nanotube

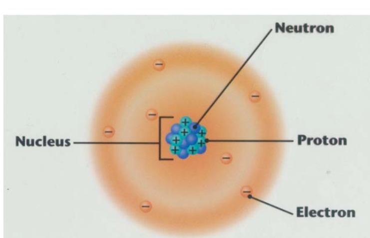


20. length of a phone book



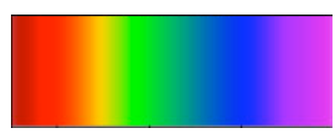
21. height of a typical NBA basketball player

22. diameter of a nitrogen atom



23. thickness of a staple

24. wavelength of visible light



Visible Light Spectrum

Cards for Number Line Activity: Units

(Uses a base 10 logorithmic scale so they can be equally spaced, except gap from 10^{-15} to 10^{-10})

10^{-15} m (1 femtometer) On $\log_{10}$ scale: -15	10^{-10} m (1 angstrom) On $\log_{10}$ scale: -10	10^{-9} m (1 nanometer) On $\log_{10}$ scale: -9
10^{-8} m (10 nanometers) On $\log_{10}$ scale: -8	10^{-7} m (100 nanometers) On $\log_{10}$ scale: -7	10^{-6} m (1 micron) On $\log_{10}$ scale: -6
10^{-5} m (10 microns) On $\log_{10}$ scale: -5	10^{-4} m (100 microns) On $\log_{10}$ scale: -4	10^{-3} m (1 millimeter) On $\log_{10}$ scale: -3
10^{-2} m (10 millimeters) On $\log_{10}$ scale: -2	10^{-1} m (100 millimeters) On $\log_{10}$ scale: -1	10^{0} m (1 meter) On $\log_{10}$ scale: 0

Image Sources for Object Cards

Accessed September 2007 through Google images (http://images.google.com).

1. Thickness of a penny: http://www.poly.edu/admissions/undergrad/images/photos/coin.jpg
2. Nucleus of an oxygen atom: http://scienzapertutti.lnf.infn.it/P2/nucle.jpg
3. Diameter of a red blood cell: http://www.biopal.com/images/Red_Bl1.jpg
4. Height of a typical 5-year-old child: http://www.lower-allen.pa.us/Parks/ParksImages/soccer%20kid%20cartoon.gif
5. Width of a proteinase enzyme: http://aiims.aiims.ac.in/ragu/aiims/departments/biophy/enzyme5.jpg
6. Length of a dust mite: http://www.owlnet.rice.edu/~psyc351/Images/DustMite.jpg
7. Width of a typical wedding ring: http://www.goldringsplus.com/GRP_img/half/RS.jpg
8. Length of an amoeba: http://gladstone.uoregon.edu/~awickert/ceramics/amoeba.jpg
9. Width of an electrical outlet cover: http://www.punchstock.com/image/comstock/4550022/large/ks2793.jpg
10. Diameter of a ribosome: http://histo.ipfw.edu/images/ribosome.gif
11. Thickness of sewing thread: http://www.techsewing.com/image/left/company-needle.gif
12. Water molecule: http://www.lenntech.com/images/Water%20molecule.jpg
13. Width of a bacterium: http://www.scientific-art.com/GIF%20files/Zoological/microbea.gif
14. Length of an apple seed: http://www.thebestlinks.com/images/thumb/5/5c/250px-Old-appleseed-d402.jpg
15. Diameter of a virus: http://www.xtec.es/~imarias/virus.gif
16. Length of a business envelope: http://www.superfineprinting.com/images/business_envs.gif
17. Diameter of a quarter: http://www.pipebombnews.com/readerimages/quarter.gif
18. Length of a human muscle cell: http://dept.kent.edu/projects/cell/tm1.jpg
19. Diameter of a carbon nanotube: http://www.csiro.au/images/activities/carbon_nanotube.jpg
20. Length of a phone book: http://www.rickleephoto.com/phone97.jpg
21. Height of a typical NBA basketball player: http://sports.tjhsst.edu/boosters/merchandise/images/basketball-player-3.gif
22. Diameter of an atom: http://web.buddyproject.org/web017/web017/ae.html
23. Thickness of a staple: http://www.unisa.edu.au/printing/images/binding/staple%20icon.jpg
24. Wavelength of visible light: http://esp.cr.usgs.gov/info/sw/clim-met/anatomy/index_nojava.html

Name__________________________________ Date______________________ Period ______

Cutting it Down Activity: Student Instructions and Worksheet

How many times do you think you would need to cut a strip of paper in half in order to make it between zero and 10 nanometers long? In this activity, you'll cut a strip of paper in half as many times as you can, and think about the process.

BEFORE you begin cutting the strip of paper, answer the following questions (take a guess):

1. How many times do you need to cut the paper in half to obtain a 10 nanometer long piece?

2. How many times do you think you can cut the paper before it becomes impossible to cut?

Now cut the strip of paper in half as many times as you can. Remember to keep track of how many cuts you make.

AFTER completing the activity, answer the following questions.

3. Were your predictions to the above two questions accurate?

4. How many times were you able to cut the paper?

5. How close was your smallest piece to the nanoscale?

6. Why did you have to stop cutting?

7. Can macroscale objects, like scissors, be used at the nanoscale?

8. Can you think of a way to cut the paper any smaller?

Name________________________________ Date_____________________ Period ______

Scale of Objects Activity: Student Instructions and Worksheet

In this activity, you will explore your perceptions of different sizes. For each of the following items, indicate its size by placing an "X" in the box that is closest to your guess.

Key:

A. Less than 1 nanometer (1 nm) [Less than 10^{-9} meter]
B. Between 1 nanometer (nm) and 100 nanometers (100 nm) [Between 10^{-9} and 10^{-7} meters]
C. Between 100 nanometers (100 nm) and 1 micrometer (1 μm) [Between 10^{-7} and 10^{-6} meters]
D. Between 1 micrometer (1 μm) and 1 millimeter (1 mm) [Between 10^{-6} and 10^{-3} meters]
E. Between 1 millimeter (1mm) and 1 centimeter (1 cm) [Between 10^{-3} and 10^{-2} meters]
F. Between 1 centimeter (1 cm) and 1 meter (m) [Between 10^{-2} and 10^{0} meters]
G. Between 1 meter and 10 meters [Between 10^{0} and 10^{1} meters]
H. More than 10 meters [More than 10^{1} meters]

	Less than 1 nm	1 nm to 100 nm	100 nm to 1 μm	1 μm to 1 mm	1 mm to 1 cm	1 cm to 1 m	1 m to 10 m	More than 10 m
Object	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
1. Width of a human hair								
2. Length of a football field								
3. Diameter of a virus								
4. Diameter of a hollow ball made of 60 carbon atoms (a "buckyball")								
5. Diameter of a molecule of hemoglobin								
6. Diameter of a hydrogen atom								
7. Length of a molecule of sucrose								
8. Diameter of a human blood cell								
9. Length of an ant								
10. Height of an elephant								
11. Diameter of a ribosome								
12. Wavelength of visible light								
13. Height of a typical adult person								
14. Length of a new pencil								
15. Length of a school bus								
16. Diameter of the nucleus of a carbon atom								
17. Length of a grain of white rice								
18. Length of a postage stamp								
19. Length of a typical science textbook								
20. Length of an adult's little finger								

Adapted from Tretter, T. R., Jones, M. G., Andre, T., Negishi, A., & Minogue, J. (2005). Conceptual Boundaries and Distances: Students' and Experts' Concepts of the Scale of Scientific Phenomena. *Journal of Research in Science Teaching*.

Name__________________________________ Date______________________ Period ______

Scale of Small Objects: Student Quiz

1. Indicate the size of each item below by placing an "X" the appropriate box.

Key:

A. Less than 1 nanometer (1nm) [Less than 10^{-9} meter]
B. Between 1 nanometer (nm) and 100 nanometers (100 nm) [Between 10^{-9} and 10^{-7} meters]
C. Between 100 nanometers (100 nm) and 1 micrometer (1 µm) [Between 10^{-7} and 10^{-6} meters]
D. Between 1 micrometer (1 µm) and 1 millimeter (1 mm) [Between 10^{-6} and 10^{-3} meters]
E. Between 1 millimeter (1 mm) and 1 centimeter (1 cm) [Between 10^{-3} and 10^{-2} meters]

	Less than 1 nm	**1 nm to 100 nm**	**100 nm to 1 µm**	**1 µm to 1 mm**	**1 mm to 1 cm**
Object	**A**	**B**	**C**	**D**	**E**
1. Width of a human hair					
2. Diameter of a hollow ball made of 60 carbon atoms (a "buckyball")					
3. Diameter of a hydrogen atom					
4. Diameter of a human blood cell					
5. Wavelength of visible light					

2. Order the following items in order of their size, from smallest to largest.

a. Width of a water molecule
d. Diameter of a gold atom
c. Thickness of a staple
d. Diameter of a virus
e. Length of an amoeba
f. Diameter of a carbon nanotube

Smallest: _________

____

____

____

____

Largest: _________

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.

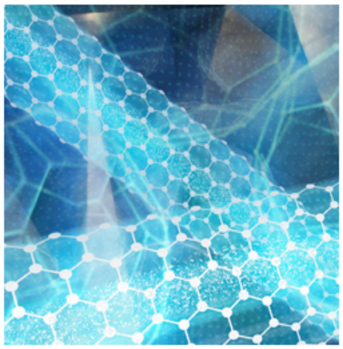
Prerequisite Knowledge and Skills

- 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

Size-Dependent Properties

How do properties change at the nanoscale?

Properties of a Material

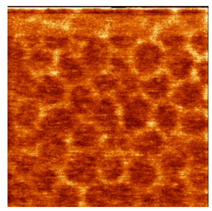
- **A property describes how a material acts under certain conditions**
- **Types of properties**
  - Optical (e.g. color, transparency)
  - Electrical (e.g. conductivity)
  - Physical (e.g. hardness, melting point)
  - Chemical (e.g. reactivity, reaction rates)
- **Properties are usually measured by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

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

Optical Properties 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

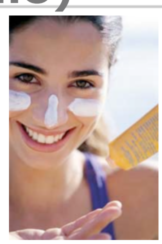


12 nanometer gold particles look red

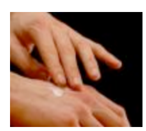
Sources: http://www.sharps-jewellers.co.uk/rings/images/bien-hccncsq5.jpg
http://www.foresight.org/Conferences/MNT7/Abstracts/Levi/

Optical Properties Example: Zinc Oxide (ZnO)

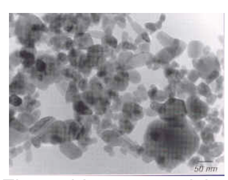
- **Large ZnO particles**
  - Block UV light
  - Scatter visible light
  - Appear white
- **Nanosized ZnO particles**
  - Block UV light
  - So small compared to the wavelength of visible light that they don't scatter it
  - Appear clear



"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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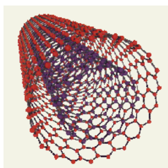
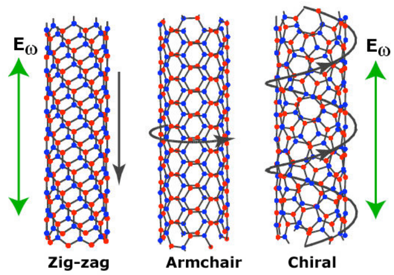
Electrical Properties Example: Conductivity of Nanotubes

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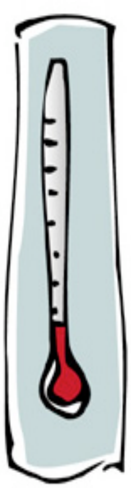
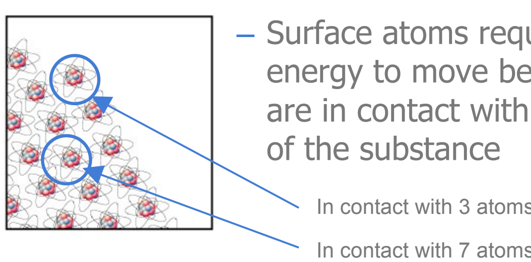
Physical Properties Change: Melting Point of a Substance



- **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



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

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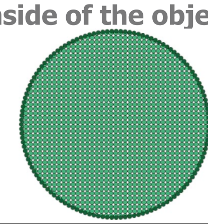
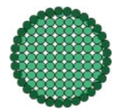
Physical Properties Example: Melting Point of a Substance II

	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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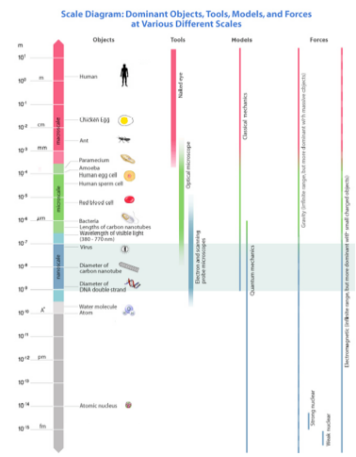
Size-Dependant Properties

Why do properties change?

NanoSense 11

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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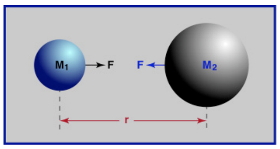
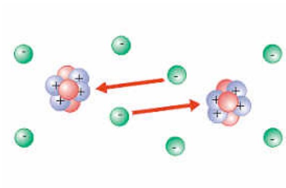
Scale Changes Everything II

- **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!

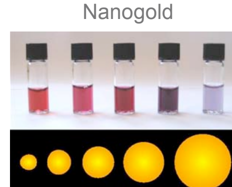
Sources: http://www.physics.hku.hk/~nature/CD/regular_e/lectures/images/chap04/newtonlaw.jpg
http://www.antonine-education.co.uk/Physics_AS/Module_1/Topic_5/em_force.jpg

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

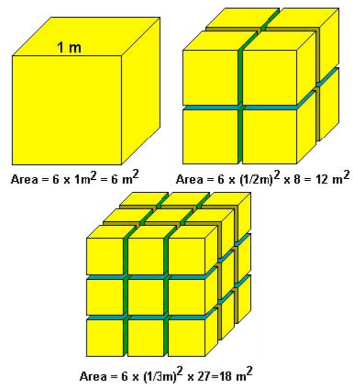
Nanogold



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;

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

Random Molecular Motion is Significant

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

The random path of a dust particle in air

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

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

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 $CuCl_2 \bullet 2H_2O$ 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 $CuCl_2 \bullet 2H_2O$ 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 ($CuCl_2 \cdot 2H_2O$). 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.

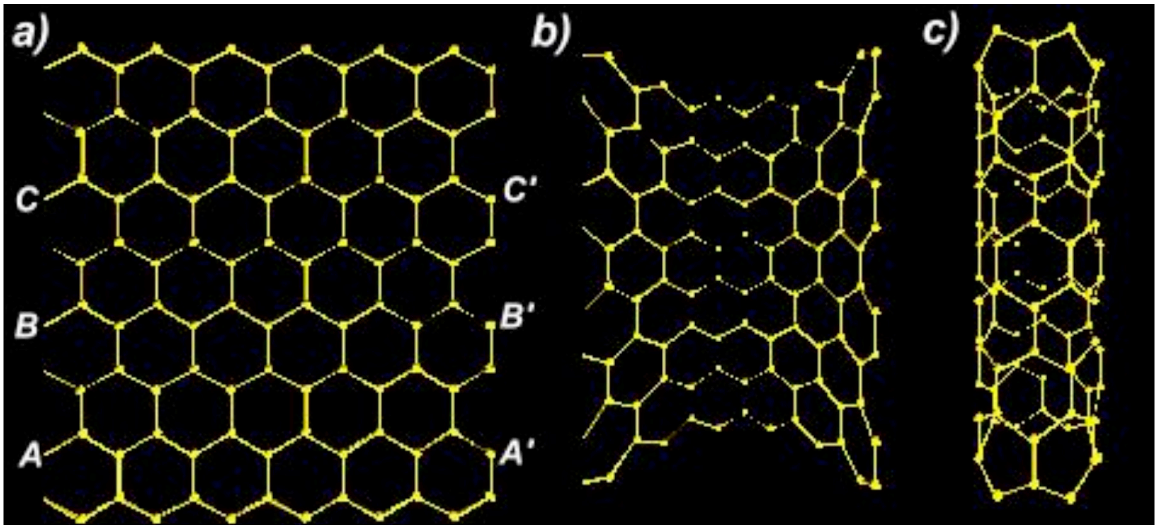


Figure 1. A plane of graphite (left) rolled up (middle) gives you a nanotube (right), matching points A with A', B with B' and so forth [1].

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.

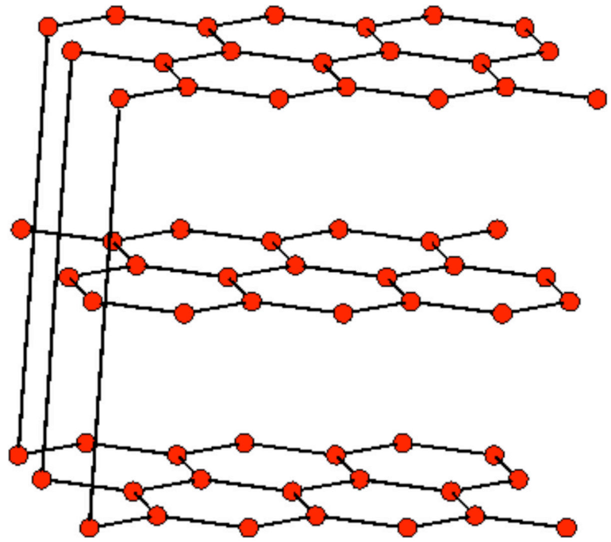


Figure 2. Layered lattice structure of graphite, with widely separated planes that are only weakly held together by weak van der Waals forces [2].

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).

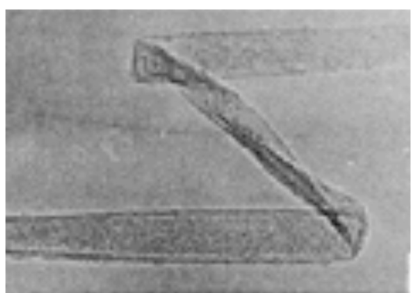


Figure 3. A severely distorted nanotube still doesn't break [3].

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!

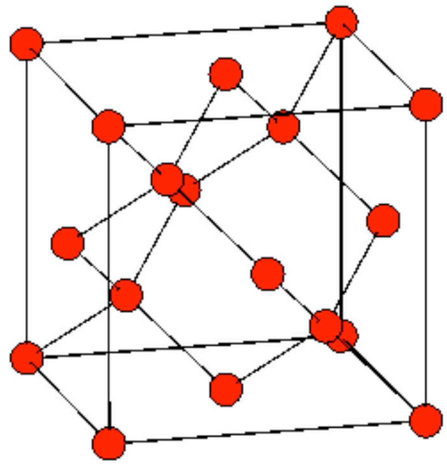


Figure 4. In diamond, each carbon atom forms 4 bonds, tetrahedrally arranged, to other carbon atoms, resulting in a very strongly bonded 3D structure. Very small diameter carbon nanotubes could be as strong as diamond. [4]

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.

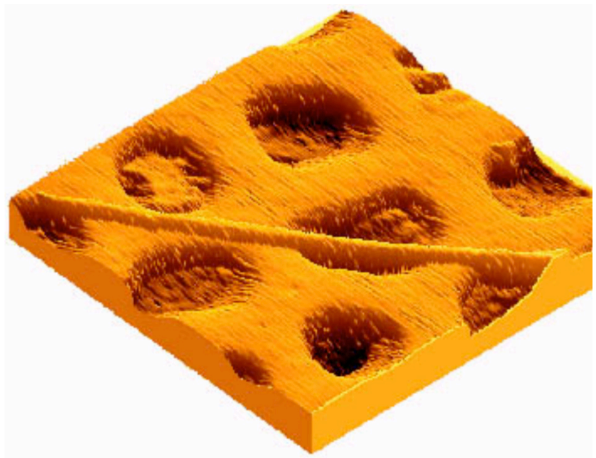


Figure 5. A carbon nanotube on a porous ceramic membrane, ready for mechanical measurements by AFM [5].

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.

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(Accessed August 2005.)

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[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

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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.

Lesson 3:
Unique Properties at the Nanoscale

Student Materials

Contents

Size-Dependant Properties: Student Reading

Overview

What is so special about nanotechnology that suddenly we have focused so much attention on this area? The new generation of scientific tools that operate on the nanoscale allow us to collect data and to manipulate atoms and molecules on a much smaller scale than we have ever been able to in the past. With these tools 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. As we study these materials in nanoscale quantities and generate theories to explain why they behave the way they do, we are learning new things about the nature of matter and developing the ability to manipulate these properties to create all sorts of new products and technologies, like the stain-repellant pants and solar power paint that we hear about in the media.

What Does it Mean to Talk About the Characteristics and Properties of a Substance?

Characteristics and properties are ways of describing different qualities of a substance and how it acts under normal conditions. Over centuries, scientists have accumulated a great deal of information about the properties of different substances (such as gold). For example we have information about gold's 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). We can use this information to predict what gold will do under different conditions and to make decisions about whether or not it is good material to use when we are building or synthesizing new materials.

How Do We Know the Characteristics and Properties of Substances?

We have come to understand the characteristics and properties of atoms and molecules by studying a pure sample of the substance in quantities big enough to measure under normal laboratory conditions. Because atoms and molecules are so extremely small, we need a huge amount in order to see them, measure their mass on a typical laboratory scale and mix specific amounts together (remember just 18 grams of water (1 mole) contains 6.022×10^{23} molecules). So when scientists make measurements of the different properties of gold, they are actually measuring the average properties based on the behavior of billions and billions of particles and not looking at the behavior of individual atoms or molecules. We have always assumed that these properties are constant for a given substance (gold always acts the same no matter how much of it you have) and in our macro-scale world experiences they have been. This means that even though we measure these properties for large numbers of particles, we assume that the results should be true for any size group of particles.

What's Different at the Nanoscale?

Using new tools that allow us to see and manipulate small groups of molecules whose size in the nanoscale, scientists have now discovered that these tiny amounts of a given substance often exhibit different properties and behaviors than larger particles of the same substance! We've seen that when the number of atoms or molecules bonded together is so small that they only occupy between 1 and 100 nanometers of space, the properties are no longer predictably the same properties that are listed in tables of "physical properties" of a substance. Consider an analogy with sand on a beach. When looking at a sandy beach from afar, the sand appears to have a uniform color and texture. As you zoom in and examine fewer grains of sand at a time, you discover that the sand is actually made up of a variety of individual colors and textures of particles. As we develop better and better tools that allow us to look at and move these grains of sand (atoms and molecules), our understanding of the nature of matter changes.

How Do These Properties Change?

The color of gold is a classic example of how properties can change based on the size of the particles. When we have an **aggregation** of gold atoms bonded together in a solid with a diameter of about 12 nanometers, we can observe the color of the nanoparticles by looking at a bunch of them suspended in water. If the atoms are in the right bonding arrangement, we see that the gold nanoparticles appear red, not gold-colored. If we add a bunch more atoms in the right arrangement, we see the particles look purple. Why? Each of the different sized arrangement of gold atoms absorbs and reflects light differently based on its energy levels, which are determined by size and bonding arrangement. This is true for many materials when the particles have a size that is less than 100 nanometers in at least one dimension.

Reaction time is another phenomenon that changes at this scale. The greater the surface-to-volume ratio that reacting substances have, the faster the reaction time. Nanosized groups of particles are so small that they have a very high surface area to volume ratio, and thus react so quickly that precise measurements of time are difficult.

For nanosized objects, some familiar properties also become meaningless. Some physical properties of substances, for example, don't necessarily make sense at the nanoscale. How would you define, much less measure, boiling temperature for a substance that has only 50 atoms? Boiling temperature is based on the average **kinetic energy** of the molecules needed for the vapor pressure to equal the atmospheric pressure. Some molecules in a pot of water on the stove will be moving fast and some will be moving more slowly. The vapor pressure results from the average force per unit area exerted by the fast moving particles in the vapor bubbles in the water. When you only have 50 molecules of water, it is highly unlikely that a bubble would form so it doesn't make sense to talk about vapor pressure.

Why Do These Properties Change at the Nanoscale?

When we look at nanosized particles of substances, there are four main things that change from macroscale objects. First, due to the small mass of the particles, gravitational forces are **negligible**. Instead **electromagnetic forces** are dominant in determining the behavior of atoms and molecules. Second, at nanoscale sizes, we need to use **quantum mechanical** descriptions of particle motion and energy transfer instead of the classical mechanical descriptions. Third, nanosized particles have a very large surface area to volume ratio. Fourth, at this size, the influences of random molecular motion play a much greater role than they do at the macroscale.

How Does the Dominance of Electromagnetic Forces Make a Difference?

As shown in Table 1, below, there are four basic forces known in nature: gravity, electromagnetism, the strong nuclear force, and the weak nuclear force. The gravitational force is the force of attraction between the masses of two objects. This force is directly proportional to the masses of the two objects and inversely proportional to the square of the distance between the objects. Because the mass of nanoscale objects is so small, the force of gravity has very little effect on the attraction between objects of this size. Electromagnetic forces are forces of attraction and repulsion between objects based on their charge and magnetic properties. These forces also increase with the charge or the magnetism of each object and decrease as the distance between the objects become greater, but they are not affected by the masses of objects. Since electromagnetic forces are not affected by mass, they can be very strong even with nanosized particles. The magnetic and electrostatic forces are very important forces that determine the behavior of substances chemically and physically at the particle level. The other two forces, the strong nuclear force and the weak nuclear force, are interactions between the particles that compose the nucleus. These forces are only significant at extremely short distances and therefore become negligible in the nanoscale range. Since electromagnetic, and not gravitational, forces are most influential at the nanoscale, nanoparticles do not behave like macrosized objects. For example, a nanosubmarine (if we could build such a thing) would behave very differently than its macroscopic counterpart. With weak gravitational, but strong electromagnetic forces, the nanosubmarine might just stick to the first surface it encountered or be repelled so that it couldn't get near another surface at all!

Table 1. The four basic forces in nature, and the scales at which these forces are influential. Note that all forces exist at all scales, but their size may be so small as to be negligible (also see the Scale Diagram).

	Gravitational Force	Electromagnetic Forces	Weak Nuclear Force	Strong Nuclear Force
Cosmic Scale 10^7 m and bigger	X	X*		
Macroscale 10^{-2} m to 10^6 m	X	X**		
Microscale 10^{-3} m to10^{-7} m	X	X		
Nanoscale 10^{-8} m to 10^{-9} m		X		
Sub-Atomic Scale 10^{-10} m and smaller			X	X

* In places like the sun, where matter is ionized and in rapid motion, electromagnetic forces are dominant.

** On a human scale, where matter is neither ionized nor moving rapidly, electromagnetism, though important, is not dominant.

How Does a Quantum Mechanical Model Make a Difference?

Classical mechanical models explain phenomena well at the macroscale level, but they break down when dealing with the very small (atomic size, where quantum mechanics is used) or the very fast (near the speed of light, where relativity takes over). For everyday objects, which are much larger than atoms and much slower than the speed of light, classical models do an excellent job. However, at the nanoscale there are many phenomena that cannot be explained by classical mechanics. The following are among the most important things that quantum mechanical models can describe (but classical models cannot):

- Discreteness of energy
- The wave-particle duality of light and matter
- Quantum tunneling
- Uncertainty of measurement

Discreteness of Energy

If you look at the spectrum of light emitted by energetic atoms (such as the orange-yellow light from sodium vapor street lights, or the blue-white light from mercury vapor lamps), you will notice that it is composed of individual lines of different colors. These lines echo the discrete energy levels of the electrons in those excited atoms. When an electron in a high-energy state falls down to a lower one, the atom emits a photon of light that corresponds to the exact energy difference of those two levels (because of the conservation of energy). The bigger the energy difference, the more energetic the photon will be, and the closer its color will be to the violet end of the spectrum. If electrons were not restricted to discrete energy levels, the spectrum from an excited atom would be a continuous spread of colors from red to violet with no individual lines.

It is the fact that electrons can only exist at discrete energy levels that prevents them from spiraling into the nucleus, as classical models predict. This quantization of energy, along with some other atomic properties that are quantized, give quantum mechanics its name.

The Wave-Particle Duality of Light and Matter

In 1690, Christiaan Huygens theorized that light was composed of waves, while in 1704, Isaac Newton theorized that light was made of tiny particles. Experiments supported each of their theories. However, neither a completely-particle theory nor a completely-wave theory could explain *all* of the phenomena associated with light!

For most light phenomena—such as reflection, interference, and polarization—the wave model of light explains things quite well. However, there are several cases in which the wave model cannot explain the phenomena that are observed, but a particle model can! One such phenomenon is called the “photoelectric effect,” discovered by Albert Einstein. The photoelectric effect happens when you shine light on the surface of a metal and some of the electrons in the metal are knocked loose (similar to shooting pellets at sandpaper). With the photoelectric effect, scientists were unable to explain how this happens using the wave model of light. But when they thought of light as small particles, they could explain this effect. So scientists began to think of light as both a particle and a wave, and depending on what experiment you do, you will see light behave in one of these two ways. It is also important to note that the wave-particle duality extends to matter as well––it is not just limited to light—and the wave nature has been observed in experiments. It may be hard to imagine something like a “matter wave,” but when you are talking about small particles such as electrons, it is possible to observe wave-like behavior.

Quantum Tunneling

Quantum tunneling is one of the most interesting phenomena to be explained by quantum mechanics. As stated above, in quantum mechanics we talk about the probability of where a particle will be. The probably of finding a particle is explained by a probability wave. When that probability wave encounters an energy barrier, most of the wave will be reflected back, but a small portion of it will “leak” into the barrier. If the barrier is small enough, the wave that leaks through will continue on the other side of it. Even though the particle doesn't have enough energy to get over the barrier, there is still a small probability that it can “tunnel” through it! It would be like trying to drive over a river after part of the bridge has washed out. You couldn’t. But imagine that the gap in the bridge is really small—much smaller than the size of the tire on your car—and the situation changes. In a car, you can imagine jumping the small gap if you are going fast enough. Similarly, electrons can jump across small gaps.

Let's say you are throwing a rubber ball against a wall. You know you don't have enough energy to throw it through the wall, so you always expect it to bounce back. Quantum mechanics, however, says that there is a small probability that the ball could go right through the wall (without damaging the wall) and continue its flight on the other side! With something as large as a rubber ball, though, that probability is so small that you could throw the ball for billions of years and never see it go through the wall. But with something as tiny as an electron, tunneling is an everyday occurrence.

Uncertainty of Measurement

People are familiar with measuring things in the macroscopic world around them. Someone pulls out a tape measure and determines the length of a table. At the atomic scale of quantum mechanics, however, measurement becomes a very delicate process. Let's say you want to find out where an electron is and where it is going. How would you do it? Get a super high-powered magnifier and look for it? The very act of *looking* depends upon light, which is made of photons, and these photons could have enough momentum that once they hit the electron, they would change the electron’s course! So by looking at (trying to measure) the electron, you change where it is. Werner Heisenberg was the first to realize that certain pairs of measurements have an intrinsic uncertainty associated with them. In other words, there is a limit to how exact a measurement can be. This is usually not an issue at the macroscale, but it can be very important when dealing with small distances and high velocities at the nanoscale and smaller. For example, to know an electron’s position, you need to “freeze” it in a small space. In doing so, however, you get poor velocity data (since you had to make the velocity zero). If you are interested in knowing the exact velocity, you must let it move, but this gives you poor position data.

Why Do the Greater Surface Area to Volume Ratios Make a Difference?

Many of the observed properties of a substance are based on intermolecular forces. When we observe a large number of particles of that substance, the majority of the particles are in the interior of the material and subject to similar forces. But this is not true of the surface particles that experience forces not only from the substance but from the surrounding material as well.

For instance, suppose we have a liter of water at room temperature. Water molecules have a great deal of **polarity**, and as such, are attracted to each other via hydrogen bonds. These intermolecular hydrogen bonds cause water to be a liquid at room temperature. They also cause water to have a relatively high surface tension, resulting in the typical drop shape of water. What about at the water molecules at the edges of the container? Does the glass beaker have the same amount and type of attraction to the water as the water molecules have to each other? No, it is slightly different. The behavior of the water at the interface between the glass and water is different than within the interior of the water, where the water molecules are only surrounded by other water molecules. What about where the water molecules come into contact with the air? Does the air, composed of mostly nitrogen, have the same attraction to the water molecules as the water molecules have to each other? Again, no. In fact, the water molecules are not generally attracted to the molecules in the air very much at all. These examples highlight the fact that if you have a small (nano) amount of a substance, a greater proportion of the substance will have interactions with surrounding materials (e.g. container, air) than if you have a great (bulk) amount of the substance. This idea of greater surface area to volume ratio for small aggregations of substances can lead to different properties being displayed than for larger aggregations that have lower surface area to volume ratios.

The importance of surfaces is demonstrated by looking at a drop of water that is resting on a waxy surface such as wax paper (see Figure 1, below). We can see that the force of attraction of the water molecules to each other (cohesive forces) is far greater than the force of attraction of the water molecules to the surface of the wax paper (adhesive forces). This results in the drop shape of the collection of water molecules, which is evidence of a high surface tension. When the surface upon which the molecules rest is changed to one in which the molecules of water are more attracted such as plastic wrap, then the shape of water collapses, because the adhesive forces between the water and the plastic wrap are strong enough to overcome the cohesive forces (which we see as surface tension) between the water molecules. You can try this at home with drops of water on wax paper and plastic wrap. This example illustrates the impact of surface features on the behavior of a substance. Nanoscale objects have a far greater amount of surface area than volume, so surface effects are far more significant in general.

Another example of the importance of surfaces is rate of reaction. Since reactions occur at the interface of two substances, when a large percentage of the particles are located on the surface, we get maximum exposed surface area, which means maximum reactivity! So nanosized groups of particles can make great catalysts.

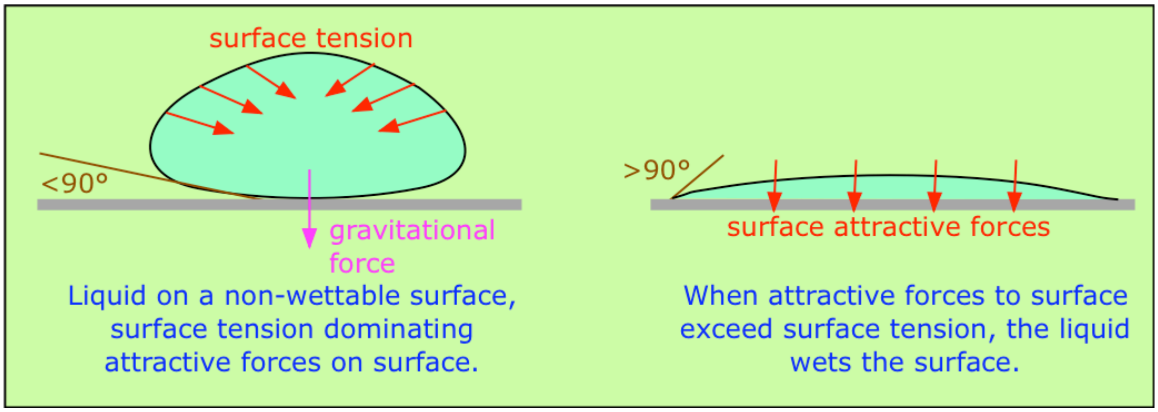


Figure 1. Surface tension and surface attractive forces for a drop of water on a non-wettable surface like glass (left), or a more attractive surface (right) [1].

Why Does Random Molecular Motion Make a Difference?

Random molecular motion is the movement that all molecules in a substance exhibit (assuming the sample is above **absolute zero**) due to their kinetic energy. This motion increases at higher temperatures (temperature is actually a macroscale measure of the average **kinetic energy** of all the particles in a substance). This motion can involve molecules moving around in space, rotating around their bonds, and vibrating along their bonds. While random kinetic motion is always present, at the macroscale this motion is very small compared to the sizes of the objects and thus is not very influential in how object behave. At the nanoscale however, these motions can be on the same scale as the size of the particles and thus have an important influence on how particles behave. For example, the imaginary nanosubmarine we talked about earlier would have its internal parts and mechanisms bending and flexing in all directions in constant random motion.

An example of how random kinetic motion can influence things is Brownian Motion [2]. Brownian Motion is the random movement of tiny particles suspended in a gas or a liquid resulting from bombardment by the fast moving particles of the gas or liquid. Think of a regular submarine in the ocean, even though it is constantly bombarded by the random kinetic motion of the water particles, it is so large that this does not significantly affect its motion through the water. Compare this to the imaginary nanosubmarine that would be constantly jostled around because the fluid molecules might be almost as big as it is!

So What Does This All Mean?

The dominance of electromagnetic force, the presence of quantum mechanical phenomena, the large surface area to volume ratio and the importance of random kinetic motion cause nanoscale sized particles to often have very different properties than their macroscale counterparts. The discovery that the properties of a substance can change with size (made possible by the new generation of scanning probe microscopes) has helped us to expand our understanding of the nature of matter and to develop new products that take advantage of the novel properties of materials at the nanoscale. As we continue to develop better tools and learn more about how and why these properties change, we will be better able to manipulate these properties to meet our needs and develop new materials and products that take advantage of these properties.

References

(Accessed August 2005.)

[1] http://www.chem1.com/acad/sci/aboutwater.html

[2] A nice animation of Brownian Motion is available through the Molecular Workbench software at http://mw.concord.org/modeler1.3/mirror/thermodynamics/brown.html

Glossary

Term	Definition
absolute zero	0 Kelvin (-273.15°C) is the coldest temperature theoretically possible at which all atomic motion stops.
aggregation	A group of something (in chemistry usually atoms or molecules).
classical mechanics	Scientific model useful for describing the behavior of macro and micro sized objects based on Newton's laws of force and motion.
electromagnetic forces	Particles with charge (or areas of charge) exert attractive or repulsive forces on each other due to this charge. Particles with magnetic properties exert attractive or repulsive forces on each other due to these magnetic properties. Since magnetism is caused by charged particles accelerating (for example by the electron "spin" in materials such as iron), these forces are considered to be two aspects of the same phenomenon and are collectively called electromagnetic forces.
kinetic energy	Energy of motion.
negligible	So small that it can be ignored.
polarity	The degree to which a molecule has a charge separation leading to one part of the molecule being partially positively charged and another part being partially negatively charged.
quantized	Something that is said to exist only in specific units and not all values along a continuum.
quantum mechanics	Scientific model useful for describing the behavior of very small particles (such as atoms and small molecules). Motion is described by probabilistic wave functions and energy can only exist in discrete (quantized) amounts.
wave function	A mathematical equation used in quantum mechanics to describe the wave characteristics of a particle. The value of the wave function of a particle at a given point of space and time is related to the likelihood of the particle's being there at the time.

Unique Properties Lab Activities: Student Directions

Lab Station A:
Serial Dilution

Purpose

The purpose of this lab is to investigate the effects of decreasing the concentration of a solution of the dual 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 any solutions or chemicals.

Materials

- A stock solution “assigned” the value of 1.0 Molar
- 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 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.

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 (nanoscopic iron particles suspended in a liquid)
- A 100-mL graduated cyclinder
- A large empty test tube, clear plastic if possible, and stopper
- A piece of iron rod, nail or washer
- Two circle magnets

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.

Lab Station C:
Bubbles Self-Assembly

Purpose

One of the methods proposed to mass manufacture nanosized objects is use nature's own natural tendency to self-assemble. 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
- Small shallow dish
- Toothpicks
- Paper towels
- Straw

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 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 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
- Granulated sugar
- A digital balance or scale, with readout to 0.1 gram, or a triple beam balance
- 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.

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
- One tablet of Alka Seltzer®
- One small mortar and pestle
- One timer or watch with seconds 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 different size beakers or flasks
- Hot plate(s) or 3 Bunsen burners
- One 100-mL graduated cylinder
- A centimeter ruler
- Tongs designed to use with glassware
- Clock or watch

Procedure

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.

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

Purpose

These activities demonstrate 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 (or a nail)
- Two sets of tongs
- Two Bunsen burners and starters
- A 2” section of steel wool

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

- $CuCl_2 \bullet 2H_2O$ crystals

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 $CuCl_2 \bullet 2H_2O$ 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.

Name___________________________________ Date______________________ Period ______

Unique Properties Lab Activities: Student Worksheet

Directions: Go to the lab stations assigned by your teacher. Follow the directions for the lab that are taped to each of the lab stations. Conduct the lab activity and record your data on this lab write up sheet. Answer the questions asked on this lab sheet. Be sure to pay special attention to the purpose of each lab.

Lab Station A: Serial Dilution

Record your data in the following chart:

Characteristics of Solution	Test tube #1 Initial	Test tube #2	Test tube #3	Test tube #4	Test tube #5 Final
Concentration/ Molarity					
Color					
Smell					

Questions

1. At what molarity of your solution was the color undetectable?

2. What pattern did you notice about the color of the solution as it decreased in strength?

3. At what molarity of your solution was the scent of your solution undetectable?

4. What pattern did you notice about the smell of the solution as it decreased in strength?

5. How does this phenomenon relate to the idea of properties of matter at the nanoscale?

Lab Station B:
Ferrofluid Display Cell Lab

Follow the directions posted at your lab station. Experiment with the ferrofluid, solid iron and magnets to discover the differences and the similarities of the two iron objects. Record your procedures (what you did), your observations (what you saw) and your discussion/conclusions (what you think about what you did and saw). Write down any questions that occurred to you regarding the objects.

Observations (ferrofluid and iron object separately):

Predictions:

Observations (interactions between magnets and: 1) ferrofluid and 2) iron object):

Discussion/Conclusions/Questions:

What difference do you think the size of the particles of iron made on their behavior?

Lab Station C:
Bubbles Self-Assembly

Conduct the lab activity according to directions posted at your lab station. Select a few instances to record in writing and sketch "before" and "after" pictures.

Drawings:

Before	After
Describe what you saw.	**Describe what happened.**

Questions

1. What do you conclude about bubbles ability to self-assemble?

2. What possible implications could the idea of self-assembly of objects have on the manufacturing of nanosized objects? You may refer back to your notes about self-assembly.

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

Conduct this lab activity according to the directions on the lab station. Record your measurements here:

	Mass Record to the nearest 0.1 gram	Observations of sugar remaining after 1st 60-seconds of stirring	Observation of sugar remaining after 2nd 60-seconds of stirring
Sugar cube			
Granulated sugar			

Questions

1. What do you conclude about the relationship between the volume and surface area on the rate of dissolving?

2. Can you think of additional experiments to conduct?

Lab Station E:
More Surface Effects… Faster Explosion?

Record the time it takes to blow the lid off of each film canister:

	Time it takes for lid to blow off
Film canister with 1/2 Alka Selzer tablet *not* crushed:	
Film canister with 1/2 Alka Selzer tablet crushed:	

What do you conclude about the surface-to-volume effects on the speed of reaction based on this experiment?

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

Record the size of each beaker and the time it takes for the water in each beaker to boil.

A	B	C	D	E	F	G	H
Type of container for the water	Diameter of surface of water (cm)	Radius of surface of water (cm)	Surface area of water (cm^2)	Surface area to volume ratio	Initial time heat is applied	Time when water boils	Total time taken for water to boil

Hints to fill out the chart:

- A is name of the type of container and the capacity, i.e. 100-mL beaker.
- B is the diameter of the surface of the water in each beaker, in centimeters; measure across the surface of the water in each container.
- C is the radius of the surface of the water in each beaker; divide the diameter (column B) by 2.
- D is the surface area of the water in each beaker (cm^2); calculate using πr^2 where π= ***pi* = 3.14** and r = radius.
- E is the surface area to volume ratio of water in each beaker, that is, the surface of the water (column D) divided by the volume of the water. Use the smallest whole number ratio; e.g., 2:1 means the surface area is twice the volume of the water.
- F, G, and H are times in minutes and seconds. H is column G minus column F.

Question

What do you conclude about the surface-to-volume ratio and the time it takes to boil?

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

Compare and contrast your observations between when the steel sample was heated and when the steel wool was heated.

What do you conclude about surface-to-volume ratios and the speed of combustion (burning)?

Speculate based on evidence: What effect(s) do you think that the increased surface area of nanosized objects make compared to bigger objects? What evidence do you have that supports your thinking?

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

Record the time that it takes for the aluminum foil to come within an estimated 80% of a completed reaction.

	Time for foil to come within 80% of completed reaction, in seconds
Flat square of aluminum foil	
Balled-up piece of aluminum foil	

What do you conclude about the effects of surface-to-volume ratio and reaction rates?

Name__________________________________ Date______________________ Period ______

Unique Properties at the Nanoscale: Student Quiz

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

a. gravitational force b. electromagnetic forces

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

_____ 2. Dominate(s) for nanosized objects.

_____ 3. Do/does not vary with mass.

_____ 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)*

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

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)*

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)*

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

Lesson 4: Tools of the Nanosciences

Teacher Materials

Contents

Tools of the Nanosciences: Teacher Lesson Plan

Orientation

This lesson focuses on two of the most widely used new probe imaging tools: the Atomic Force Microscope (AFM) and the Scanning Probe Microscope (SPM).

- The Scanning Probe Microscopy PowerPoint explains how these two tools work, the difference between them, and what you can see and build with them.
- The Student Reading on Seeing and Building Small Things provides more details on scanning probe tools and describes self-assembly as another way to build things.
- The Black Box Activity gives students the opportunity to use probes to "see" the unknown surface of a mystery box and consider firsthand the challenges of using probes.
- The Seeing and Building Small Things Quiz tests students knowledge of scanning probes and self-assembly.

You may want to extend this lesson beyond one day to incorporate building a model of an AFM. Two different strategies are suggested in the Optional Extensions for Exploring Nanoscale Modeling Tools: Teacher Notes.

Essential Questions (EQ)

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

(Numbers correspond to learning goals overview document)

4. How do we see and move things that are very small?
5. Why do our scientific models change over time?

Enduring Understandings (EU)

Students will understand:

(Numbers correspond to learning goals overview document)

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)

5. Explain how an AFM and a STM work, and give an example of their use.

Prerequisite Knowledge and Skills

- Familiarity with atoms and 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*: Student reading: Seeing and Building Small Things	*30 min*	Photocopies of student reading
	Teacher Resource: Scanning Probe Microscopy: Teacher Reading	*30 min*	One copy for the teacher
Day 1 (50 min)	Show the Scanning Probe Microscopy: PowerPoint Slides, using teacher's notes as talking points. Highlight the AFM and STM, and the relationship between new tools and the ability to gather new data and to innovate using new technologies.	20 min	Introduction to Nanoscience: PowerPoint Slides Computer and projector
	Conduct Black Box Activity	20 min	Prepare black boxes according to teacher instructions Photocopies of the Black Box Activity: Student Instructions and Questions
	Discuss Black Box Activity and student reading: Seeing and Building Small Things	10 min	
Day 2 (50 min)	Optional: Extensions for Exploring Nanoscale Modeling	Will vary	Teacher notes
	Student Quiz: Seeing and Building Small Things	10 min	Photocopies of Student Quiz Teacher Key for correcting Student Quiz

Scanning Probe Microscopy: Teacher Reading

Introduction

In 1981, Gerd Binnig and Heinrich Rohrer, two IBM scientists working in Zurich, Switzerland, invented the first scanning tunneling microscope (STM). They were awarded the Nobel Prize in physics for this work, which gave birth to the development of a new family of microscopes known as scanning probe microscopes (SPM). All SPMs are based on scanning a probe just above a sample surface while monitoring the interaction between the probe and surface. The different types of interactions that are monitored are what characterize the different types of scanning probe microscopes. The STM monitors the electron tunneling current between a probe and a conducting sample surface, while the more recently developed atomic force microscope (AFM) monitors the Van der Waals forces of attraction or repulsion between a probe and a sample surface. The advantage of this new family of scanning probe microscopes is that we are able to image and manipulate matter as small as 0.1 Angstroms (.01 nm). So how do these probe microscopes work to obtain images down to the atomic level?

The Scanning Tunneling Microscope (STM)

The STM is based upon a quantum mechanical phenomenon known as electron tunneling. Tunneling is the movement of an electron through a classically forbidden potential energy state. A common analogy is that of a car of a roller coaster at the bottom of a large hill. Based on classical mechanics, one would predict that the car would not make it over the hill if it did not have enough kinetic energy. However, viewed from a quantum mechanical viewpoint, an electron is no longer just a particle having either enough or not enough energy to make it past a potential energy barrier. Rather, an electron also exhibits wave like properties, and as such, the electron is no longer confined to strict energy boundaries. As a wave, there is a small but finite probability that the electron can be found on the classically forbidden side of the potential energy barrier. When an electron behaves in such a manner, it is said to have tunneled.

Electron tunneling is the core concept behind the STM. In the STM, a probe, commonly referred to as the tip, is brought close to the surface of a sample being examined (see Figure 1). The energy barrier that is classically forbidden is the gap (air, vacuum) between the tip and the sample. When the tip and the sample are brought within a distance of around 1 nm of each other, tunneling occurs from the tip to the sample or vice versa, as long as the sample is an electrical conductor. A current can then be measured as result of electrons tunneling.

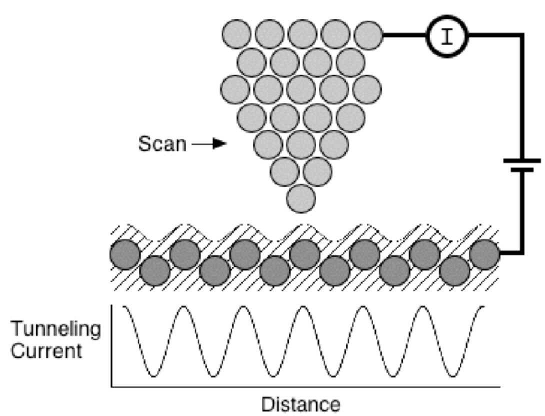


Figure 1. Tip and surface and electron tunneling [1]

The magnitude of the tunneling current is very sensitive to the gap distance between the tip and the sample. The tunneling current drops off exponentially with increased gap distance. If the distance is increased by as small as 1 Angstrom, the current flow is decreased by an order of magnitude.

Imaging of the surface of a sample based on electron tunneling current can be carried out in one of two ways:

1. Constant height mode: The tunneling current is monitored as the tip is scanned across a sample. The changes in current give rise to an image of the topography of the sample.
2. Constant current mode: The tip is moved up and down as the surface changes in order to keep the actual tip-to-sample height constant. This maintains a constant current, and the movement of the tip is monitored as it is scanned across a sample. The changes in tip height give rise to an image of the topography of the sample. This mode is more commonly used.

STM Tips

Because of the dependence of the tunneling current upon the tip to sample distance is exponential, it is then only the closest atom on the tip of the STM probe that will interact with the sample surface (see Figure 2). Tunneling occurs between the electrons of a single atom on the tip of an STM probe, and one atom at a time on the sample surface.

How are these tips made? It is actually not as difficult as one would think. STM tips can be made by etching a pit into a crystalline surface such as silicon to make a mold. Then a thin layer of the material to be used to make the tip, such as silicon nitride, is placed onto the silicon mold, filling the pit. When the silicon nitride layer is removed from the silicon that contained the etch pit, an STM tip is produced. Tungsten and platinum are also commonly used to make STM tips.

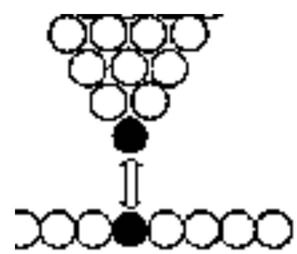


Figure 2. An STM tip [2]

But how do we make sure that the tip is one atom sharp? Actually, is not necessary to worry about placing one atom at the very tip. Looking closer at the tip, you will see that there is invariably a crystalline structure there (see Figure 3). And if you were to look even closer, at the atomic level, you would in fact see a truly atomic tip. Again, because electron-tunneling current changes so dramatically with distance (an increase in distance of one Angstrom causes a decrease in tunneling current by a power of ten), that one atom at the tip will produce a tunneling current. Interference from surrounding atoms is negligible due to their distance from the sample surface.

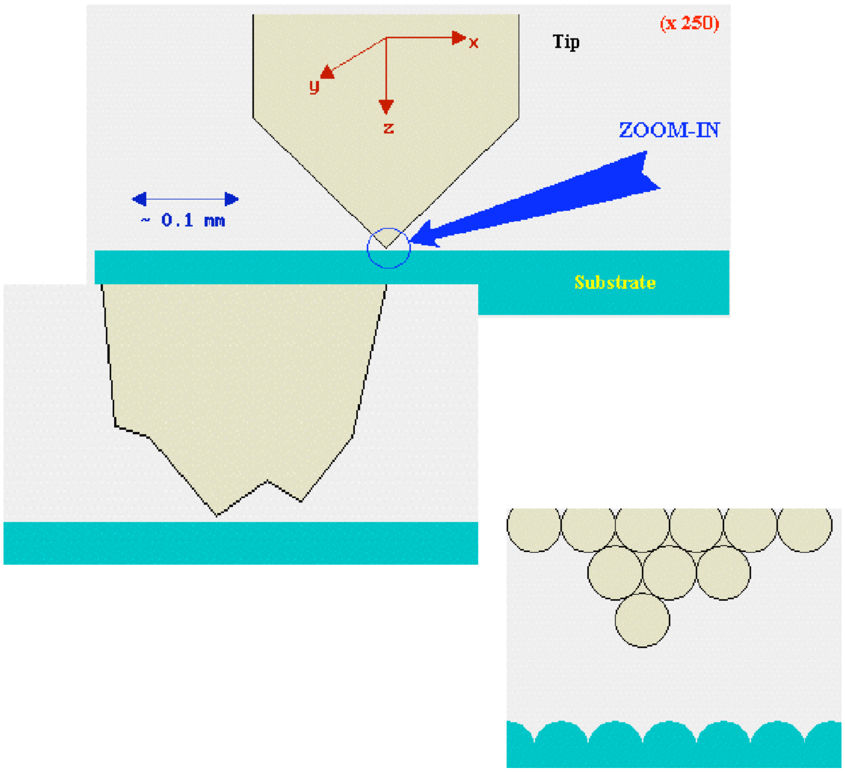


Figure 3. Zoom in of tip [3]

Moving the STM Tip

In order to get a precise picture of the topography of a sample, the STM tip must scan across the surface in increments as small as Angstroms. It is impossible for human manipulation to move a probe at such a small scale. To solve this problem, piezoelectric materials are used to move the STM tip in increments that the human hand cannot.

Piezoelectric materials are materials that change shape when a voltage is applied. Some examples of piezoelectric materials are ceramics, quartz, human bone, and lead zirconium titanate, which is typically used in STMs. The STM tip is connected to a tube containing piezoelectric material. Voltage can then be applied to the piezoelectric material, causing fine changes in dimension, which causes the tip to move Angstroms at a time.

Putting It All Together

The operation of an STM is based on electron tunneling, which occurs when a tip approaches a conducting surface at a very small distance (1nm). The tip is mounted onto a piezoelectric tube, which allows tiny, controlled movements of the tip by applying a voltage to the tube. As the tip is scanned along a sample in this way, the tip maintains a constant current or a constant tip-to-sample-surface distance. The resulting movement of the tip is recorded and displayed revealing a surface picture at the atomic level (see Figure 4).

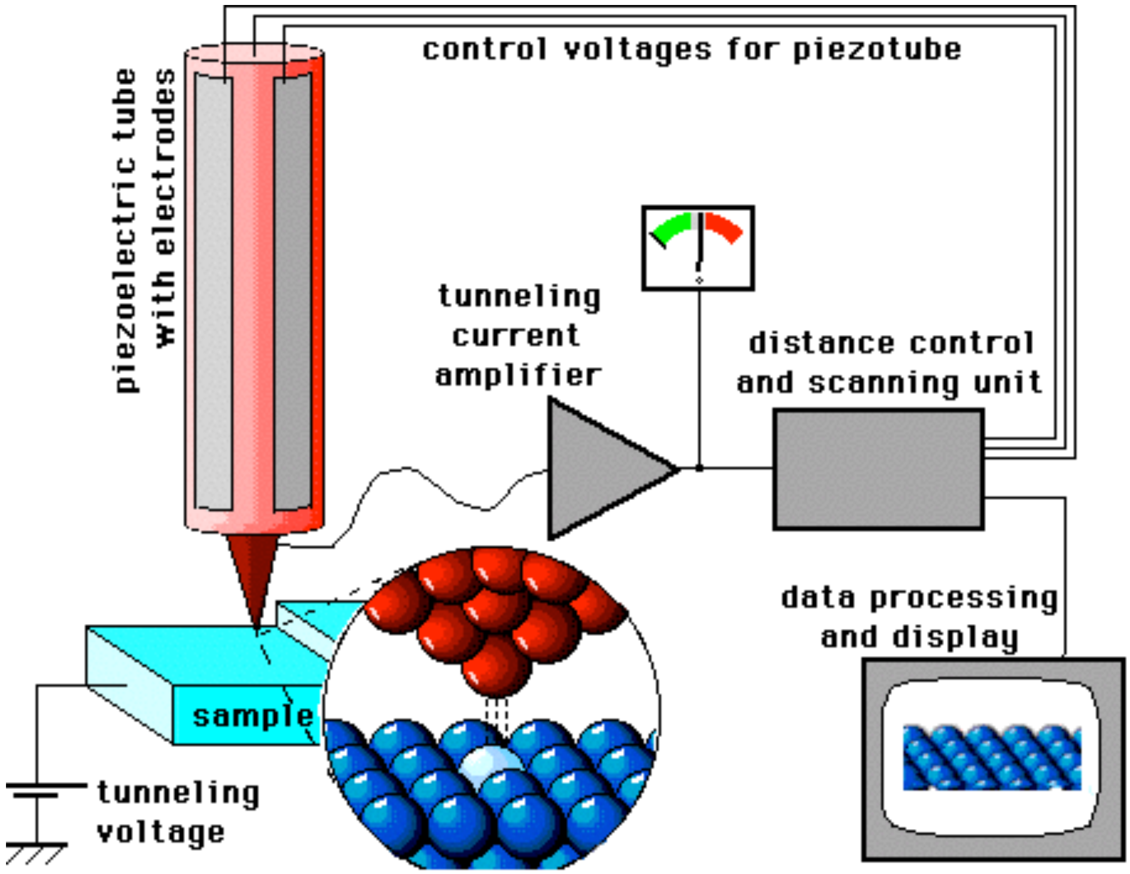


Figure 4. Diagram of an STM [4]

Challenges in using an STM

In practice, several challenges arise when using the scanning tunneling microscope. One is vibrational interference. Since the tip of an STM is only a nanometer or so from the surface of a sample, it is easy to crash the tip into the sample. Any minor cause for vibration, such as a sneeze or motion in the room, could result in damaging the tip.

Contamination from particles in the air such as dust can also be problematic. A small dust particle is made up of millions of atoms, and would certainly interfere with the microscope performance. For this reason, STMs are commonly run under vacuum. The chemical reactivity of particles in air with the tip or sample surface is another reason to scan samples under vacuum.

One other drawback of the STM is that it is only useful for producing images of conducting or semiconducting materials because it relies on the tunneling movement of electrons. It is not effective in producing images of nonconducting materials. Another scanning microscope, the atomic force microscope, allows us to see nonconducting materials at the atomic level.

The Atomic Force Microscope (AFM)

The atomic force microscope (AFM) is another type of scanning probe microscope in the same family as STMs. It's based on the same idea: a probe tip scanning a sample to create an image of a sample's topography. But rather than monitoring the electron tunneling current between a scanning tip and sample, the AFM monitors the forces of attraction and repulsion between a scanning tip and a sample.

In an AFM, the scanning tip is attached to a spring or cantilever that allows the tip to move as it responds to forces of attraction or repulsion it has for a sample surface. The cantilever is a beam around 0.1 mm long and a few microns thick. It is supported on one end and has the scanning tip hanging from it on the other. Parallel to how the STM works, as the AFM tip is scanned over the sample at constant force, the tip attached to a cantilever or spring moves up and down, producing an image of the topography. Piezoelectric materials are again used to control the small distances needed to see a sample at the atomic level.

A laser beam is used to measure the movement of the cantilever (see Figure 5). The laser beam is positioned so that it reflects off the backside of the cantilever, which usually has a gold coating, behaving like a mirror. The reflected beam hits a detector that magnifies and monitors the movement of the cantilever.

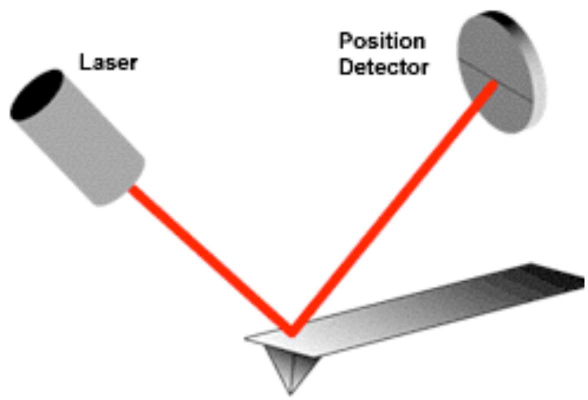


Figure 5. Laser used to measure cantilever movement [5]

Deciding on a tip to use requires careful consideration. Because it is the mechanical movement of the tip itself that ultimately produces the image, the size of the tip used must be chosen carefully. It must be small enough to get into all the "nooks and crannies" of a sample surface. The sharpness of a tip must be appropriately chosen.

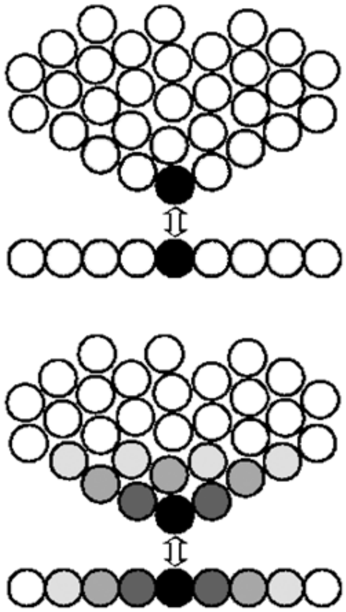


Figure 6. Interatomic interaction for STM (top) and AFM (bottom); shading shows interaction strength [6]

In addition, unlike the STM where only the one atom sharp tip registers surface topography due to electron tunneling occurring only over short distances, with the AFM, several atoms near the tip will play a role (see Figure 6). Forces of attraction and repulsion occur over longer distances. Several atoms near the tip of an AFM will be attracted or repulsed by several atoms on the sample surface.

The AFM is also more versatile than the STM. It can be adjusted to monitor different forces depending on the type of contact the tip has with a sample as well as the type of tip used to scan a sample. Depending on the force being monitored, different images of a sample surface can then be produced.

For example, an AFM can be in "contact mode," where the tip is in direct contact with a surface sample. This measures van der Waals forces. A drawback of contact mode is the lateral frictional force that would exist as a tip is "dragged" over a sample. To address this, some samples are scanned using the "tapping mode" which oscillates the cantilever tip, while tapping a sample. The benefit of this mode is that frictional forces are dramatically reduced.

Another mode, called the "lift" mode, allows one to image a surface by monitoring magnetic forces and electrostatic forces. In addition, because the tip is attached to a cantilever or spring, lateral movement and angled deflection can also be measure to produce an image.

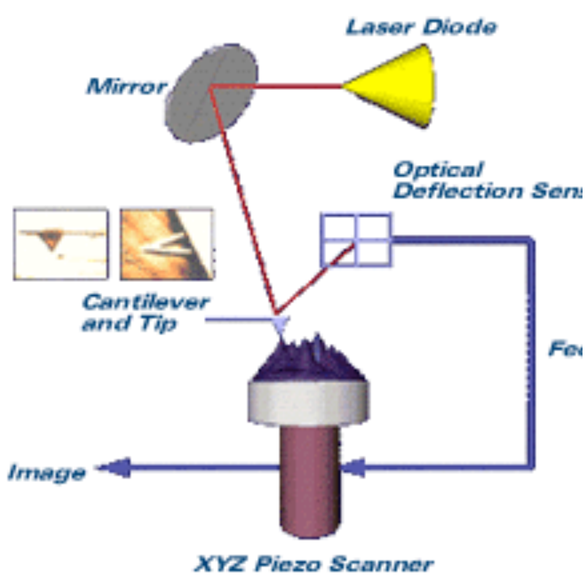


Figure 7. How the AFM works [7]

Using STMs and AFMs in Nanoscience

Not only do STMs and AFMs allow us to see images at the nanoscale level, they also enable us to manipulate matter at this level. By applying small voltages to an STM tip, atom-by-atom manipulation is possible. Being able to change the orientations of atoms (or clumps of atoms) as well as deposit or remove atoms (or clumps of atoms) is just the beginning of the development of many future applications.

References

(Accessed August 2005.)

[1] http://mrsec.wisc.edu/Edetc/modules/MiddleSchool/SPM/MappingtheUnknown.pdf

[2] http://mechmat.caltech.edu/~kaushik/park/3-3-0.htm

[3] http://www.chem.qmw.ac.uk/surfaces/scc/scat7_6.htm

[4] http://www.iap.tuwien.ac.at/www/surface/STM_Gallery/stm_animated.gif

[5] http://www.nanoscience.com/education/AFM.html

[6] http://mechmat.caltech.edu/~kaushik/park/3-3-0.htm

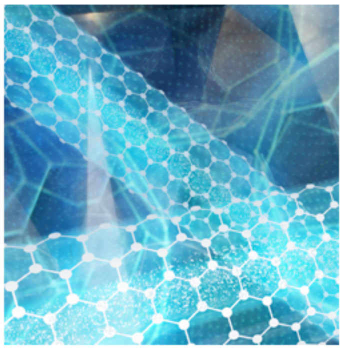
[7] http://physchem.ox.ac.uk/~rgc/research/afm/afm1.htm

Additional Resources

http://weizmann.ac.il/Chemical_Research_Support/surflab/peter/afmworks/

http://home.earthlink.net/~rpterra/nt/probes.html

http://www.lotoriel.de/pdf_uk/all/pni_tutorial_uk.pdf



Scanning Probe Microscopy

"Seeing" at the nanoscale

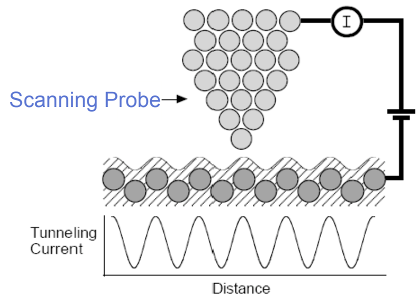
NanoSense
the basic sense behind nanoscience

Scanning Probe Microscopes (SPMs)

- **Monitor the interactions between a probe and a sample surface**
- **What we "see" is really an image**
- **Two types of microscopy we will look at:**
  - Scanning Tunneling Microscope (STM)
  - Atomic Force Microscope (AFM)

Scanning Tunneling Microscopes (STMs)

- **Monitors the *electron tunneling current* between a probe and a sample surface**
- **What is electron tunneling?**
  - Classical versus quantum mechanical model
  - Occurs over very short distances

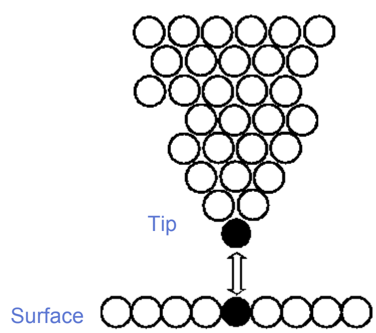


Tip and surface and electron tunneling

Source: http://mrsec.wisc.edu/Edetc/modules/MiddleSchool/SPM/MappingtheUnknown.pdf

STM Tips

- **Tunneling current depends on the distance between the STM probe and the sample**



Tunneling current depends on distance between tip and surface

Source: http://mechmat.caltech.edu/~kaushik/park/3-3-0.htm

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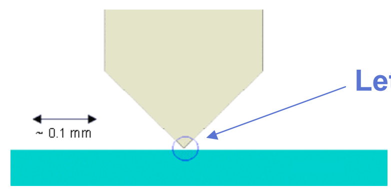
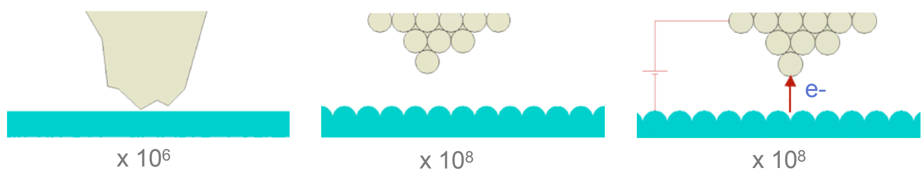
STM Tips II

- How do you make an STM tip "one atom" sharp?





Source: http://www.chem.qmw.ac.uk/surfaces/scc/scat7_6.htm

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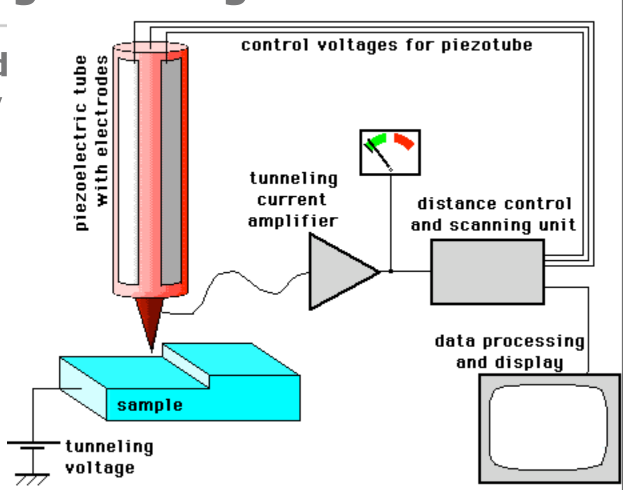
Putting It All Together

- The human hand cannot precisely manipulate at the nanoscale level
- Therefore, specialized materials are used to control the movement of the tip



How an STM works
(click to play or see URL below)

NOTE: Tip-sample distance and tip movement are in the nanometer range and vastly exaggerated here!

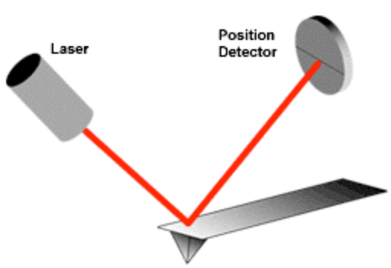
Source: http://www.iap.tuwien.ac.at/www/surface/STM_Gallery/stm_animated.gif

Challenges of the STM

- **Works primarily with conducting materials**
- **Vibrational interference**
- **Contamination**
  - Physical (dust and other pollutants in the air)
  - Chemical (chemical reactivity)

Atomic Force Microscopes (AFMs)

- **Monitors the forces of attraction and repulsion between a probe and a sample surface**
- **The tip is attached to a *cantilever* which moves up and down in response to forces of attraction or repulsion with the sample surface**
  - Movement of the cantilever is detected by a laser and photodetector



Laser and position detector used to measure cantiliver movement

Source: http://www.nanoscience.com/education/AFM.html

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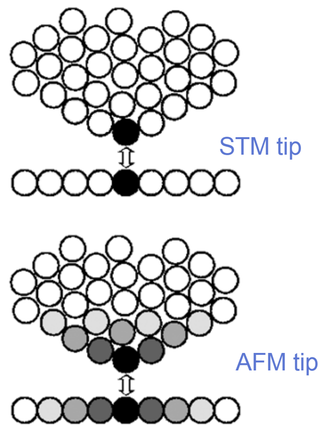
AFM Tips

- The size of an AFM tip must be carefully chosen



Interatomic interaction for STM (top) and AFM (bottom). Shading shows interaction strength.

Source: http://mechmat.caltech.edu/~kaushik/park/3-3-0.htm

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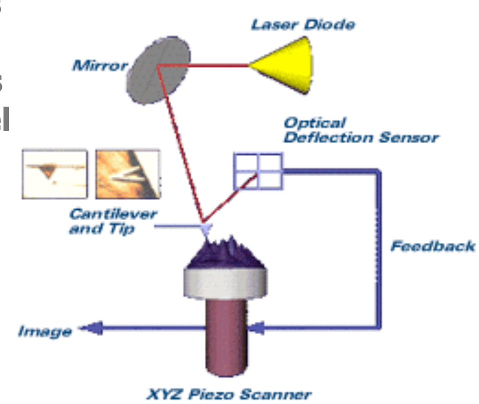
The AFM

- Specialized materials are again used to manipulate materials at the nanoscale level



Source: http://physchem.ox.ac.uk/~rgc/research/afm/afm1.htm

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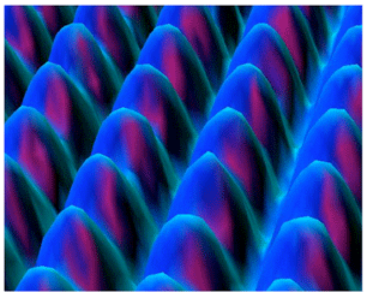
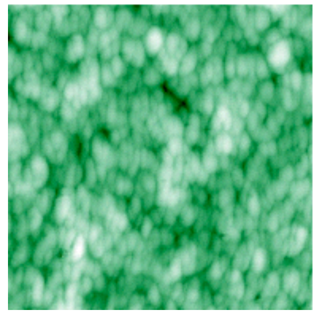
So What Do We See?



Nickel from an STM



ZnO from an AFM

Sources: http://www.almaden.ibm.com/vis/stm/blue.html
http://www.asylumresearch.com/ImageGallery/Mat/Mat.shtml#M7

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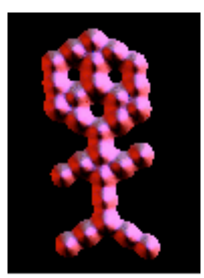
And What Can We Do?

- **Using STMs and AFMs in Nanoscience**
  - Allows atom by atom (or clumps of atoms by clumps of atoms) manipulation as shown by the images below

Xenon atoms



Carbon monoxide molecules

Source: http://www.almaden.ibm.com/vis/stm/atomo.html

Scanning Probe Microscopy Slides: Teacher Notes

Overview

This series of slides introduces students to two major types of scanning probe microscopy that are used to see and manipulate matter at the nanoscale level. It is recommended that you read the accompanying teacher background reading, as it provides more in-depth explanations of the ideas addressed in the PowerPoint slides.

Slide 1: Scanning Probe Microscopy

Explain to the students that we will cover how scanning probe microscopes can be used to help us "see" at the nanoscale level.

Slide 2: Two Types of Scanning Probe Microscopes (SPMs)

All SPMs monitor some type of interaction between a probe and a sample surface. The type of interaction that is monitored depends on the type of SPM you are using.

- STMs monitor an electrical current between a probe and a sample surface, meaning it is useful for seeing the surface of *conducting* materials.
- AFMs monitor the force of attraction or interaction between a probe and a sample surface, and can be used to see the surface of all types of materials.

You may also want to discuss that what we are "seeing" is really an image and how this image may be similar or different to what we can see with other tools, such as light microscopes.

Slide 3: Scanning Tunneling Microscopes (STMs)

In the classical view of the electron, an electron is a particle that will be found in locations where it has enough energy to exist.

In the quantum mechanical view of the electron, an electron is a wave that primarily exists in areas of high probability. However, due to its wave nature, there is a finite possibility that the electron may exist in a location beyond high probability energy states, thus allowing for tunneling. Tunneling occurs at very short distances, around 1 nm.

You may talk about the two different microscopy modes: constant height vs. constant current. You may also address the fact that the double-headed arrow signifies that electron tunneling can occur tip to probe or probe to tip, depending on how the instrument is biased. But electrons do not tunnel in both directions at the same time.

Slide 4: STM Tips

Only the atom at the very tip of an STM tip will experience electron tunneling with a sample surface, because electron tunneling is exponentially dependent upon distance.

Slide 5: STM Tips II

A series of pictures zooming in on an STM tip shows that a one atom sharp tip will almost inevitably be naturally occurring.

Slide 6: Putting it All together

The animation runs a little slow; you might want to talk over it.

http://www.iap.tuwien.ac.at/www/surface/STM_Gallery/stm_animated.gif

The specialized material is referencing piezoelectric materials. You may choose to go into this or skip it depending on your class level.

Slide 7: Challenges of the STM

Vibrational interference might include sneezing or other air movement in the room that could cause crashing of the tip into the sample surface. Running the STM in a vacuum addresses some of the challenges.

Slide 8: Atomic Force Microscopes (AFMs)

You might want to start by defining what a cantilever is. AFMs monitor the forces of attraction between a scanning probe tip and a sample surface. Because movement of the tip occurs at the nanoscale level—which the human eye cannot detect without aid—the movement of a laser beam detects movement in the cantilever.

Slide 9: AFM Tips

Unlike STM tips where the electron tunneling will selectively occur between the closest atom on the tip and a sample surface, the AFM tip measures interactions between several atoms at the tip. For this reason, the size of the tip must be carefully chosen. Smaller and sharper tips yield finer resolution and vice versa. You might want to refer back to the Black Box activity and some of the follow-up questions that were addressed or discussed there.

Slide 10: The AFM

The AFM is a bit more versatile than the STM. Technology has found new ways to monitor different force interaction between a tip and a sample surface, leading to their respective images at the atomic level.

Slide 11: So What Do We See?

These images of nickel and ZnO are taken from IBM research labs.

Slide 12: And What Can We Do?

In general, manipulation is done by applying voltages and charges to an STM tip.

Black Box Lab Activity: Teacher Instructions & Key

Purpose

To use different probes to determine the layout of objects on the bottom surface of a closed box, and to consider the limitations and challenges in using probes to "see." The idea is to get students thinking about how the scanning probe microscopes give us a picture of the surface of atoms, and to consider some of the basic challenges in scanning probe microscopy.

Materials

- One black box
- One pencil and magnet probe
- One cotton swab probe
- One skewer probe

How to Make a Black Box

1. Glue different objects to the bottom of each box. Use a variety of objects in various arrangements to make this as challenging an activity as appropriate. The class as a whole can have the same surface, or each pair can have their own unique surface. Use objects of different compositions and shapes—such as pastas, magnets, macaroni noodles, and Q-tips—and glue them in pattern such as a square, circle, or triangle. Do not use cotton balls, since they come apart after many jabs with probes. Also, use a strong super glue or rubber cement to keep the objects (especially the magnets) in place. When arranging, keep in mind that we want the students to be able to deduce the bottom surface more accurately when using the smaller barbecue skewer probe. An arrangement that would allow this differentiation (such as macaroni noodles 1/4 cm apart instead of 2 ping pong balls 5 inches apart) is favorable.
2. Cut a small (e.g., 1/2 inch) hole in the top of the box, through which students will insert the probes. A square box will work best, since it will allow students to reach all parts of the bottom surface from a center top hole. If shoeboxes are used, cut more than one hole in the top so that all areas of the bottom surface can be reached.
3. For the pencil and magnet probe, glue an eraser-size magnet onto the eraser end of the pencil. With this probe, students will find strong pulls and repulsions by the magnets that are at the bottom of your black box.
4. Prepare enough black boxes and probes for each pair to work with their own set.

Student Instructions

1. Obtain from your teacher a box, pencil and magnet probe, a cotton swab probe, and a barbeque skewer probe.

2. Place the pencil and magnet probe into the center hole, and determine as best you can what the surface of the bottom of the box looks like. Draw your best guess below.

A rough sketch of the surface, highlighting any magnets.

3. Replace the pencil and magnet probe with the cotton swab probe, using the swab end as the probe. Is there any additional information you are able to conclude about the surface of the bottom of the box? Draw your best guess below.

   A more specific sketch, perhaps identifying some general shapes of the objects.

4. Replace the cotton swab probe with the barbecue skewer probe, using the pointed end of the skewer as the probe. Is there any additional information you are able to conclude about the surface of the bottom of the box? Draw your best guess below.

   A more specific drawing, identifying the layout and composition of the surface.

Questions

1. Describe the technique you used to investigate the surface of the bottom of the box.

   A systematic survey of the bottom surface, scanning back and forth, row by row.

2. What kinds of information about the bottom surface were you able to deduce?

   The layout of the bottom of the box, as well as the composition of the various materials on the bottom surface of the box.

3. How accurate do you think your drawing is?

   The basic layout and the general composition of the different objects are pretty accurate. The specific shapes and the texture of the surfaces are some properties that could not accurately be interpreted.

4. What could you do to get a better idea of what the bottom surface looks like, besides opening the box?

   Use a finer probe, use your fingers as a probe to increase sensitivity, scan the bottom surfaces in smaller increments.

5. What if a ping-pong ball was attached to the probing end of the skewer? How might this have affected your interpretations?

   A ping-pong ball would have revealed general information, such as the general layout. The resolution would have been less specific and less accurate compared with what the barbecue skewer told us.

6. What difficulties did you encounter in using this probing technique to “see” the unknown? Or what challenges could there be in using such a technique?

   The tip of the probe could be damaged, or the bottom surface could be damaged during probing. The size of the probe must be appropriately small.

Activity adapted from: http://mrsec.wisc.edu/Edetc/modules/MiddleSchool/SPM/MappingtheUnknown.pdf

Seeing and Building Small Things Quiz: Teacher Key

1. Name the scanning probe instrument that uses electrical current to infer an image of atoms. Briefly describe how it works.

Scanning tunneling microscope (STM): As the STM tip is scanned across a surface, the STM measures the flow of electron tunneling current between the tip and the surface. This tunneling current depends strongly on the distance between the probe tip and the sample, and thus is sensitive to peaks and valleys of the surface. The changes in the strength of this current can be used to create an image of the surface.

2. Name the scanning probe instrument that reacts to forces inherent in atoms and molecules to infer an image of atoms. Briefly describe how it works.

Atomic force microscope (AFM): As the AFM tip is scanned across a surface, the AFM measures the tiny up and down movements of the tip that occur due to the electromagnetic forces of attraction and repulsion between the tip and the sample. This movement can be used to create an image of the surface.

3. Scanning probe instruments can also be used to create things atom by atom. Briefly summarize the downside of using such tools to create an aspirin tablet.

Creating an aspirin table one atom at a time would be very expensive and slow; it would take millions of years just to create one tablet because there are a huge number (more than one trillion billion) of aspirin molecules in an aspirin tablet.

4. How does dip pen nanolithography (DPN) work? Using a drawing in your explanation.

DPN writes structures to a surface the same way that we write ink using a pen. A reservoir of atoms or molecules (the "ink") is stored in the tip of an AFM. The tip is then moved across a surface, leaving the molecules behind on the surface in specific positions. (Drawing should show the transfer of molecules from the AFM tip to the surface.)

5. Name two things in nature that are created by self-assembly processes.

Many answers are possible here; for example, a bubble, snowflake, crystal growth, DNA, cell walls and functions, etc.

6. Circle true or false for each of the following.

E-beam lithography is a type of self assembly.	True	**False**
One type of self-assembly is crystal growth.	**True**	False
Nanotubes can be grown like trees from seed crystals.	**True**	False
The rules governing self-assembly are fully understood.	True	**False**

Optional Extensions for Exploring Nanoscale Modeling Tools: Teacher Notes

Exploring AFM Models

Wooden AFM

Mr. Victor Brandalaise and Dr. Maureen Scharberg at San Jose State University have developed a large-scale wood model of an atomic force microscope (AFM). The cost for the materials for this model is approximately $30. The wood cantilever has a sewing needle tip, and on top of the cantilever near the tip is a mirror. A laser pointer is positioned to beam light from above the cantilever. As the tip skims along a surface, such as copper pellets, a piece of textured plastic, or popcorn kernels, the laser beam reflects the surface onto a piece of paper. From behind the piece of paper, which is attached to a piece of transparent plastic, students can easily trace the amplified surface. For more information, contact Dr. Scharberg at (408) 924-4966 or email scharbrg@pacbell.net

LEGO AFM

As part of their "Exploring the Nanoworld" program, the Materials Research Science and Engineering Center on Nanostructured Materials and Interfaces (MRSEC) at the University of Wisconsin offers materials showing how to assemble a large-scale AFM with LEGO bricks; see http://mrsec.wisc.edu/Edetc/LEGO/PDFfiles/2-1app.PDF.

To learn more about exploring the nanoworld with LEGO bricks, or how to order LEGO kits for this purpose for your classroom, see http://mrsec.wisc.edu/Edetc/LEGO/index.html

How Such Models Could Be Used

Using such models, your students could examine a range of surfaces composed of pure or mixed materials. Students could compare traces from the different instruments and, given unidentified traces made by other students, try to infer the surface type. These activities could lead to discussions of measurement error, identification of impurities in samples, and the advantages and appropriateness of different imaging techniques for different surface types. These activities would provide a revealing view of the instruments and principles behind them.

For assessment, students could be asked to depict the functionality of an AFM using the ChemSense Animator tool available for free download at http://chemsense.org. Using ChemSense, students could draw the components of the AFM and create an animation that predicts what will happen as the cantilever scans across a surface of a sample. In tandem, they could be asked to draw an associated graph that illustrates the changes in force over the surface as the tip moves in their animation. Students would describe the output of the instrument terms of magnetic repulsion or energy distribution.

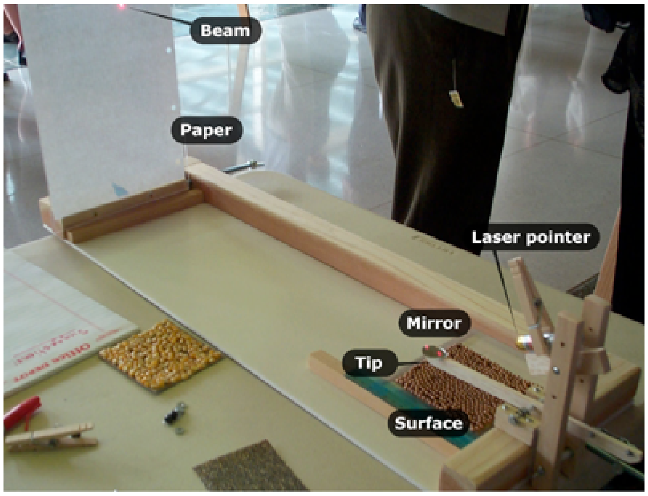


Figure 1. Wood AFM model.

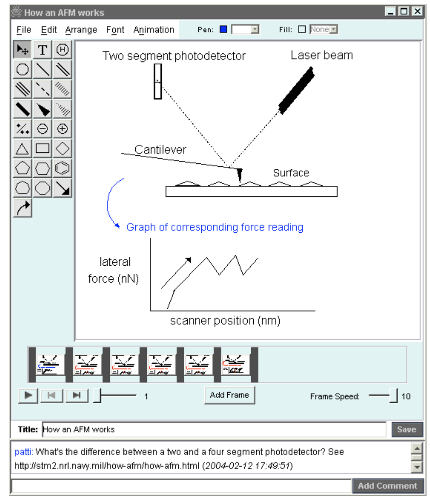


Figure 2. Screen shot of a ChemSense assessment activity.

Exploring Self Assembly

(Source: White paper by Bob Tinker, The Concord Consortium)

The Molecular Workbench (MW) software, available at http://molo.concord.org/software for both Macintosh and Windows platforms, can be used to model nano-engineering concepts such as self assembly. Self-assembly is a nano-engineering concept borrowed from biological systems. The underlying mechanisms for self-assembly are the general van der Waals mutual attraction of all atoms, Coulomb forces due to charged regions of molecules, and shape.

Shape and Smart Surfaces

To build in the impact of shape, MW has “Smart Surfaces” that can be drawn by the user. These surfaces are actually chains of MW atoms linked together with elastic bonds and covered by a flexible surface that hides the atoms. Charge can be added to the periphery of a Smart Surface. The result is a good approximation to a large molecule. It can hold its general shape, but it does vibrate, respond to temperature, and have both long-range Coulomb forces as well as short-range van der Waals forces.

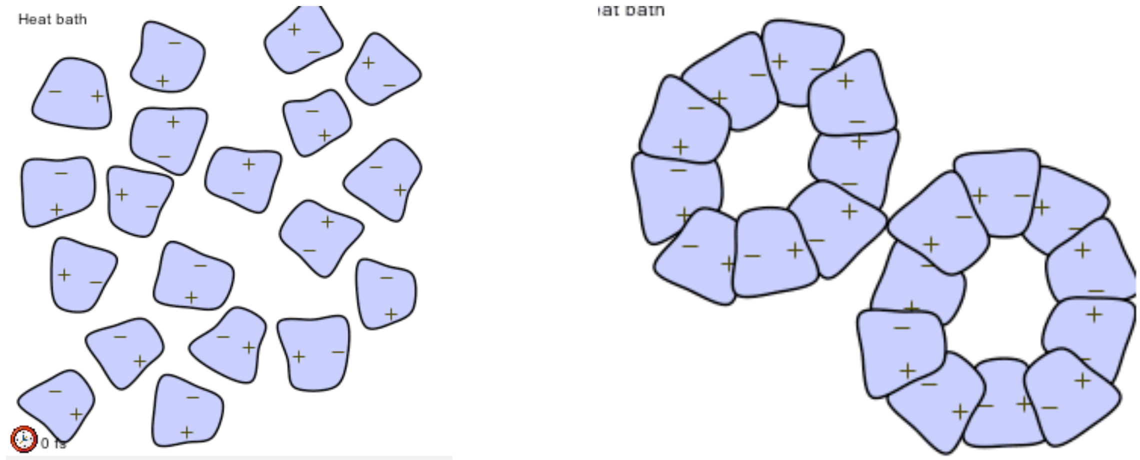


Figure 3. Smart surfaces can be made to self-assemble. Above is an example of a particularly interesting kind of self-assembling object based on nine identical sub-units.

To run the “Smart Surfaces” model, launch MW from http://molo.concord.org/software and then look for “self assembly” under “Recent models and activities.”

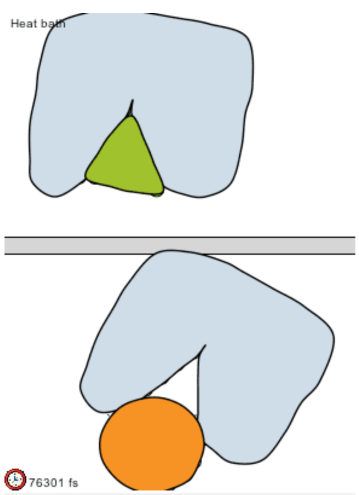


Figure 4. The importance of shape in docking.

The model at the left demonstrates the importance of shape in docking, something similar to self-assembly. This model can be heated to separate the two molecules and then both the ball and triangle bounce around. On cooling, the triangle eventually finds its way back to the complementary surface through a random walk that takes quite a long time. This gives one an appreciation for the time-scale of molecular events of this type.

Lesson 4:
Tools of the Nanosciences

Student Materials

Contents

Name___________________________________ Date______________________ Period ______

Black Box Lab Activity: Student Instructions & Worksheet

Purpose

To use different probes to determine the layout of objects on the bottom surface of a closed box, and to consider the limitations and challenges in using probes to "see."

Materials

- One black box
- One pencil and magnet probe
- One cotton swab probe
- One skewer probe

Instructions

1. Obtain from your teacher a box, pencil and magnet probe, a cotton swab probe, and a barbecue skewer probe.

2. Place the pencil and magnet probe into the center hole, and determine as best you can what the surface of the bottom of the box looks like. Draw your best guess below.

3. Replace the pencil and magnet probe with the cotton swab probe, using the swab end as the probe. Is there any additional information you are able to conclude about the surface of the bottom of the box? Draw your best guess below.

4. Replace the cotton swab probe with the barbecue skewer probe, using the pointed end of the skewer as the probe. Is there any additional information you are able to conclude about the surface of the bottom of the box? Draw your best guess below.

Questions

1. Describe the technique you used to investigate the surface of the bottom of the box.

2. What kinds of information about the bottom surface were you able to deduce?

3. How accurate do you think your drawing is?

4. What could you do to get a better idea of what the bottom surface looks like, besides opening the box?

5. What if a ping-pong ball was attached to the probing end of the skewer? How might this have affected your interpretations?

6. What difficulties did you encounter in using this probing technique to “see” the unknown? Or what challenges could there be in using such a technique?

Seeing and Building Small Things: Student Reading

How Do You See and Build Things That Are So Small?

Although **Richard Feynman** launched the idea of **nanotechnology** way back in his 1958 speech, it wasn't until decades later that we were actually able to create things at the **nanoscale**. Why did it take so long? Because we didn't have the right tools until then. We had lots of tools to make small devices, but these tools didn't operate at a small enough scale—until now!

Scanning Probe Instruments

In recent years, new tools have been developed that make it easier for scientists to measure and manipulate atoms and molecules. Some of the first tools were scanning probe instruments, developed in the early 1980s. The idea behind these instruments is simple: If you close your eyes and slide the tip of your finger across a surface, you can tell tree bark from satin from peanut butter. The tip of your finger acts like a probe that measures the force that it takes to move across the surface. It's easier to slide your finger across satin than across peanut butter because the peanut butter exerts a drag force that pulls the finger back. You can even rearrange the peanut butter by dragging it this way.

Scanning probe instruments are like your finger, but reduced to the nanoscale. They have probes that slide across surfaces and measure properties like force—but the very tip of such probes are often only a single atom in size! With this tiny tip, these instruments can "feel" the force of one atom on the surface and from that, be able to tell what kind of atom it is. They can even be used to move atoms around and arrange them in a preferred order, just as you can move peanut butter with your finger.

What Are Some Types of Scanning Probe Instruments?

One type of scanning probe instrument is the atomic force microscope (AFM). The AFM uses a tiny tip that moves in response to the **electromagnetic forces** between the atoms of the surface and the tip. Tips are usually made of silicon, though sometimes carbon nanotubes are used for the tip. As the tip is scanned across a surface, the AFM measures the tiny upward and downward deflections of the tip necessary to remain in close contact with the surface. Alternately, the tip can be made to vibrate and intermittently "tap" the surface. In this case, the AFM senses when the tip (briefly) contacts the surface and uses this information to generate a topographical images.

Another type of scanning probe instrument is the scanning tunneling microscope (STM). With this instrument, the "tunneling" of electrons between the tip and the atoms of the surface being viewed creates a flow of electrons (a current). Tungsten is often used for STM tips because it is strong, electrically conductive, and easy to electro-chemically etch to a fine point. Carbon nanotubes may also prove to be suitable for use as STM tips, given their remarkable electrical and mechanical properties.

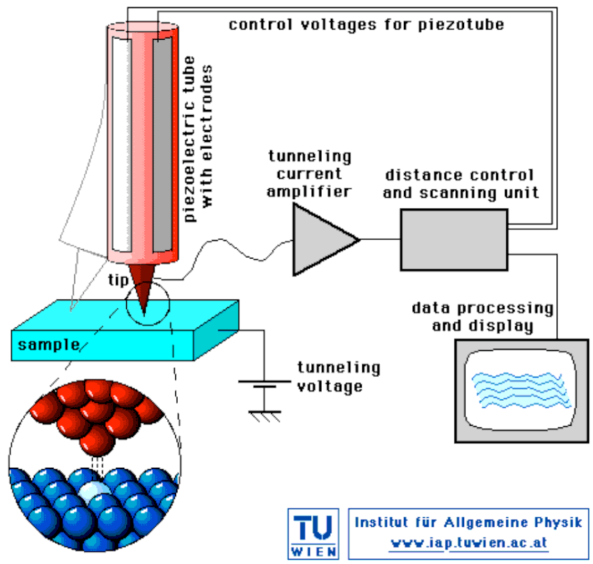


Figure 1. Scanning tunneling microscope (STM) [1].

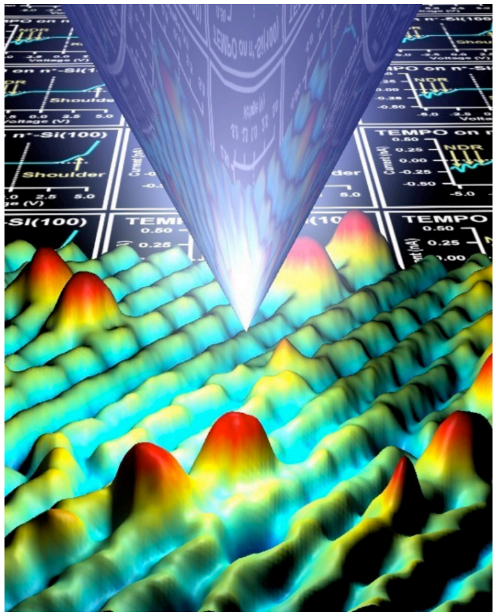


Figure 2. Tip of a scanning probe instrument [2].

The AFM was invented to overcome 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.

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.

You Mean I Can *Move* Things Too?

But these microscopes can do much more than just "see": their tips can form bonds with the atoms of the material they are scanning, and *move* the atoms. Manipulation of atoms by an STM is done by applying a tiny pulse of charge through the tip of the instrument. For example, hydrogen can be removed from hydrogen-silicon bonds by scanning a STM tip over the surface while applying rapid pulses, which pulls the bonds apart.

Once an atom has been lifted, it can be deposited elsewhere. Using this method with xenon atoms, IBM created the tiniest logo ever in 1990. In 1996, the tiniest abacus was also created by arranging **buckyballs** on a copper surface.

Figure 3. Nano logo [3].

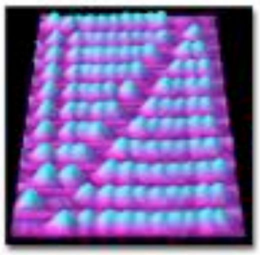


Figure 4. Nano abacus [4].

Is This a Good Way to Make Things?

Creating devices and materials atom-by-atom is more than an academic exercise; it paves the way for the next wave of nanotechnology research. But producing a material one atom at a time is not great for satisfying mass demand, because it's expensive and slow. For example, using the fastest techniques we have today, it would still take over 60 million years to assemble one aspirin table atom-by atom, because there are a lot of aspirin molecules (about 3.5×10^{20} to be precise) in one aspirin tablet that would need to be assembled! So how else can we manipulate atoms?

What is Nanoscale Lithography?

A "lithograph" originally referred to an image made by carving a pattern into a stone, applying ink to the stone "mask," and then pressing the inked stone onto a paper. Lithography was first used in the 18th century by artists to print music and art on paper. The lithography process was adapted in the late 20th century to imprint patterns on semiconductor materials to be used as integrated circuits. In this case, the "mask" is made using chemical methods, and light "ink" passes through the mask to produce the circuit structures.

Nanoscale lithography adapts this process once again. But nanoscale lithography can't use visible light, because the wavelength of visible light is 400 **nanometers**, which is too big. It would be like trying to engrave your name on your watch with a shovel. Doing lithography on the nanoscale requires new methods.

One way to get around the problem of visible light waves being too big is to use smaller wavelengths of light at the nanoscale. But smaller wavelength light is also higher energy, and that energy could cause damage to a feature that you're trying to make. One of the early approaches to get around this problem was to use electrons instead of light. This is called e-beam lithography.

A more recent (and some argue, better) approach is to use something called dip pen nanolithography (DPN), which writes structures to a surface the same way that we write ink using a pen. In this approach, a reservoir of atoms or molecules (the "ink") is stored in the tip of an AFM. The tip is then moved across a surface, leaving the structures behind on the surface.

In this schematic of DPN, the wiggly lines above the substrate are the atoms and molecules that make up the "nanoink."

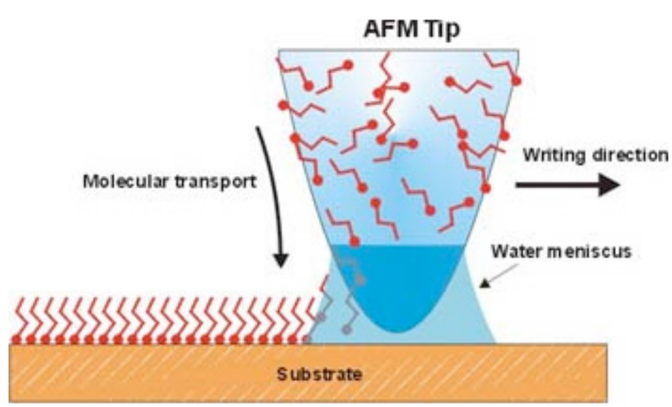


Figure 5. Transporting molecules to a surface using dip-pen nanolithography [5]

These techniques are clearly better and faster than manipulating atoms one by one. But it still would be wonderful if we could just mix chemicals together and have nanostructures just assemble themselves? This is what nature does, after all.

What is Self Assembly?

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. In cells, DNA is self-assembled from the atomic particles available to the cell. **Photosynthesis** is a process of self assembly. In fact, all the functions of the cell are variations of self assembly.

Is Self Assembly a Good Way to Build Things?

Through self assembly, large structures can be prepared without the individual tailoring that is required in the methods mentioned above. Just toss atoms or molecules onto a surface, and stand back. Of course it’s not quite that simple—they don’t always go in the places that you want them to! But because of the large number of structures one could create quickly with this method, it will probably become the most important nanofabrication technique.

One particular type of self-assembly is crystal growth. This technique is used to “grow” **nanotubes** and **nanowires**. 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!

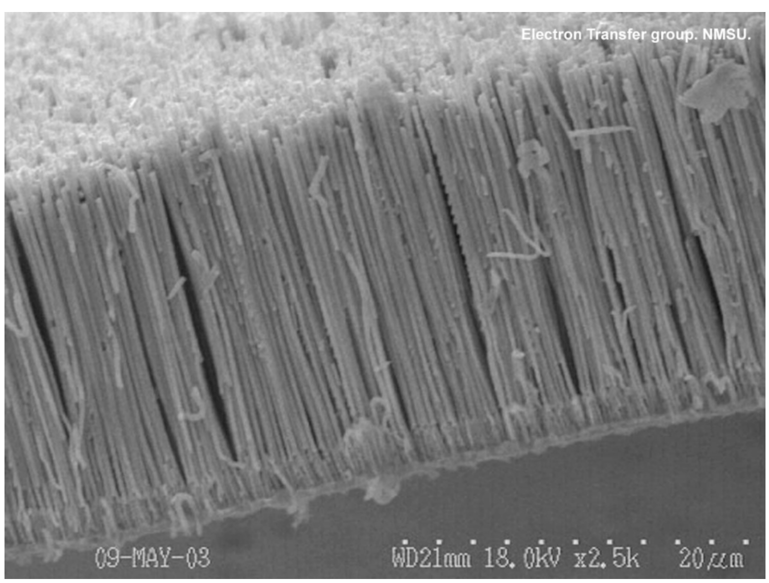


Figure 6. Growing nanotubes like trees [6]

Summary

The size limit of the smallest features you can create depends on the tools that you use. We've seen that STM and AFM's can be used to measure and manipulate atoms, either in a one-by-one fashion, or through nanolithography methods like DPN. In contrast to this "positional" approach, self-assembly is carried out largely by nature, usually through a chemical reaction. We can use self-assembly to create new structures if we set up the conditions just right. Although there are many examples of self-assembly around us in nature (including ourselves!), the rules that govern these assemblies are not fully understood. Our ability to create nanostructures improves as we gain understanding of biological self-assembly, the chemical development of new molecular structures, and the physical development of new tools.

References

(Accessed August 2005.)

[1] http://www.iap.tuwien.ac.at/www/surface/STM-Gallery/stm_schematic.html

[2] http://www.hersam-group.northwestern.edu/cover-figure.jpg

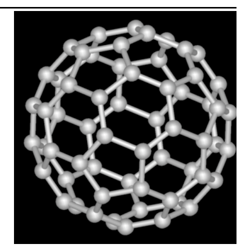
[3] http://www.almaden.ibm.com/ vis/stm/images/stm10.jpg

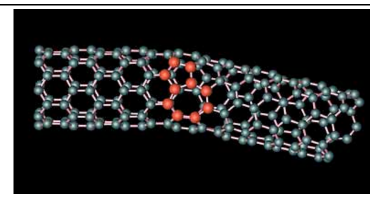
[4] http://www.research.ibm.com/atomic/nano/roomtemp.html

[5] http://www.chem.northwestern.edu/~mkngrp/dpn.htm

[6] http://www.chemistry.nmsu.edu/~etrnsfer/nanowires/

Glossary

Term	Definition
buckyball	A soccerball-shaped molecule made up of 60 carbon atoms. Also known as Buckminsterfullerene.  Image from http://en.wikipedia.org/wiki/Image:Fullerene-C60.png
electromagnetic forces	Particles with charge (or areas of charge) exert attractive or repulsive forces on each other due to this charge. Particles with magnetic properties exert attractive or repulsive forces on each other due to these magnetic properties. Since magnetism is caused by charged particles accelerating (for example by the electron "spin" in materials such as iron), these forces are considered to be two aspects of the same phenomenon and are collectively called electromagnetic forces.

Feynman, Richard (1918-1988)	One of the most influential American physicists of the 20th century, Richard Feynman greatly expanded the theory of quantum physics and received the Nobel Prize for his work in 1965. He also helped in the development of the atomic bomb and was an inspiring lecturer and amateur musician.  Image from http://en.wikipedia.org/ wiki/Image:Nobel_feynman.jpg
nanometer	One-billionth of a meter (10-9m). The prefix 'nano' is derived from the Greek word for dwarf because a nanometer is very small. Ten hydrogen atoms lined up side-by-side are about 1 nanometer long.
nanopowder	A dry collection of nanoparticles.
nanoscale	Refers to objects with sizes in the range of 1 to 100 nanometers in at least one dimension.
nanotechnology	The design, characterization, production and application of structures, devices and systems that take advantage of the special properties at the nanoscale by manipulating shape and size.
nanotubes	Carbon nanotubes are cylindrical molecules made up of carbon bonded in a hexagonal formation. They are unusually strong, efficient conductors of heat and exhibit unique electrical properties. These characteristics make them potentially useful in extremely small scale electronic and mechanical applications.  Image from http://en.wikipedia.org/wiki/ Image:Louie_nanotube.jpg
nanowires	A "nanowire" is a wire of dimensions of the order of a nanometer (10 − 9 meters). At these scales, quantum mechanical effects are important - hence such wires are also known as "quantum wires".
photosynthesis	A biochemical process in which cells in plants, algae, and some bacteria use light energy to convert inorganic molecules into ATP (a high energy storage molecule) which they can use for energy later.
polymer	A generic term used to describe a substantially long molecule. This long molecule consists of structural units and repeating units strung together through chemical bonds.
supersaturation	Supersaturation (or oversaturation) refers to a solution that due to special conditions contains more of the dissolved material than could be dissolved by the solvent under normal circumstances.

Name_________________________________ Date_____________________ Period ______

Seeing and Building Small Things: Student Quiz

1. Name the scanning probe instrument that uses electrical current to infer an image of atoms. Briefly describe how it works.

2. Name the scanning probe instrument that reacts to forces inherent in atoms and molecules to infer an image of atoms. Briefly describe how it works.

3. Scanning probe instruments can also be used to create things atom by atom. Briefly summarize the downside of using such tools to create an aspirin tablet.

4. How does dip pen nanolithography (DPN) work? Using a drawing in your explanation.

5. Name two things in nature that are created by self-assembly processes.

1:

2:

6. Circle true or false for each of the following.

E-beam lithography is a type of self assembly.	True	False
One type of self-assembly is crystal growth.	True	False
Nanotubes can be grown like trees from seed crystals.	True	False
The rules governing self-assembly are fully understood.	True	False

Lesson 5:
Applications of Nanoscience

Teacher Materials

Contents

Applications of Nanoscience: Teacher Lesson Plan

Orientation

This lesson introduces students to applications of nanoscience, explores how nanoscale science and engineering could improve our lives, and describes some potential risks of nanotechnology.

- The Applications of Nanoscience PowerPoint slides illustrate a variety of current and potential nanotechnology applications.
- The What's New Nanocat project gives students the opportunity to work in groups to research an application of nanoscience, prepare and present it, and give peer feedback.

Essential Questions (EQ)

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

(Numbers correspond to learning goals overview document)

3. Occasionally, there are advances in science and technology that have important and long-lasting effects on science and society. What scientific and engineering principles will be exploited to enable nanotechnology to be the next big thing?
6. What are some of the ways that the discovery of a new technology can potentially 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.

Key Knowledge and Skills (KKS)

Students will be able to:

(Numbers correspond to learning goals overview document)

3. Describe an application (or potential application) of nanoscience and its possible effects on society.
4. Compare a current technology solution with a related nanotechnology-enabled potential solution for the same problem

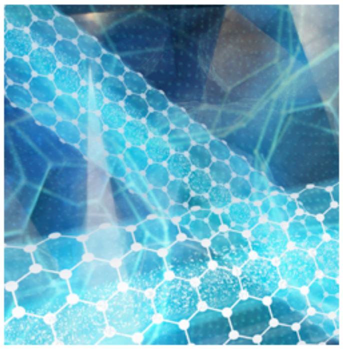
Prerequisite Knowledge and Skills

- Ability to research topics independently (for optional activity).

Related Standards

- NSES Science and Technology: 12EST2.2, 12EST2.4
- History and Nature of Science. 12GHNS3.3
- NSES Science as Inquiry: 12ASI2.3

Day	Activity	Time	Materials
Day 1 (35 min)	Show the PowerPoint slides: Applications of Nanoscience, using teacher's notes as talking points. Describe and discuss interactively with students the examples shown of possible applications. Try to stimulate student interest!	20 min	PowerPoint slides: Applications of Nanoscience Computer and projector
	What's New Nanocat? Assign or allow students to choose the nanotechnology topic they want to investigate for the project. Students will work in groups of 3 or 4.	15 min	What's New Nanocat? Teacher Instructions and Rubric Prepare a sign-up sheet for each student group to indicate their chosen topic and the names of all students in their group.
Days 2-4 (full class)	Students conduct independent investigation and prepare a presentation, in groups, on chosen/assigned topic.	3 days	Computers with internet connection, journal articles, library. Materials for making a poster presentation using PowerPoint or posters.
Day 5 (full class)	Students make their presentations to the class. Class members discuss and ask questions.	1 day	Copies of the What's New Nanocat? Poster Session: Peer Feedback Form Scoring rubric will be used to score student presentations. May require computer and projector for those students wishing to present their topic using PowerPoint. You may want to display paper posters or share PowerPoint slide presentations.



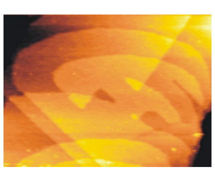
Applications of Nanoscience

How might nanoscale science and engineering improve our lives?

NanoSense
the basic sense behind nanoscience

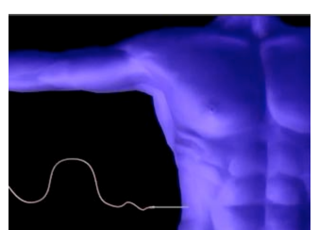
Potential Impacts of Nanotechnology

- **Materials**
  - Stain-resistant clothes
- **Health Care**
  - Chemical and biological sensors, drugs and delivery devices
- **Technology**
  - Better data storage and computation
- **Environment**
  - Clean energy, clean air



Thin layers of gold are used in tiny medical devices

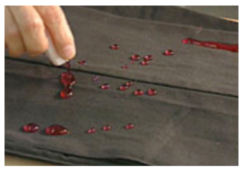
Carbon nanotubes can be used for H fuel storage



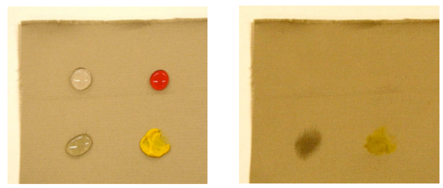
Possible entry point for nanomedical device

Materials: Stain Resistant Clothes

- **Nanofibers create cushion of air around fabric**
  - 10 nm carbon whiskers bond with cotton
  - Acts like peach fuzz; many liquids roll off



Nano pants that refuse to stain; Liquids bead up and roll off



Nano-Care fabrics with water, cranberry juice, vegetable oil, and mustard after 30 minutes (left) and wiped off with wet paper towel (right)

Sources: http://www.sciencentral.com/articles/view.php3?article_id=218391840&cat=3_5
http://mrsec.wisc.edu/Edetc/IPSE/educators/activities/nanoTex.html

Materials: Paint That Doesn't Chip

- **Protective nanopaint for cars**
  - Water and dirt repellent
  - Resistant to chipping and scratches
  - Brighter colors, enhanced gloss
  - In the future, could change color and self-repair?

Mercedes covered with tougher, shinier nanopaint

Sources: http://www.supanet.com/motoring/testdrives/news/40923/

Environment: Paint That Cleans Air

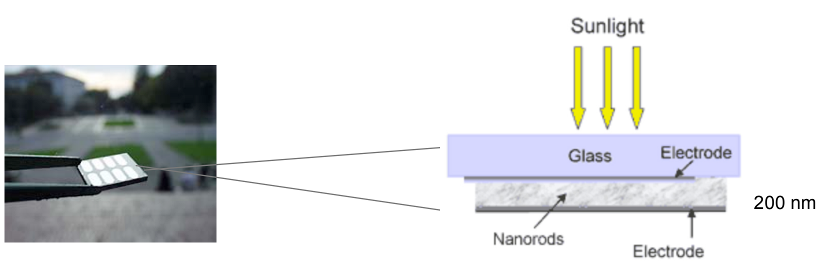
- **Nanopaint on buildings could reduce pollution**
  - When exposed to ultraviolet light, titanium dioxide (TiO2) nanoparticles in paint break down organic and inorganic pollutants that wash off in the rain
  - Decompose air pollution particles like formaldehyde

Buildings as air purifiers?

Sources: http://english.eastday.com/eastday/englishedition/metro/userobject1ai710823.html

Environment: Nano Solar Cells

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

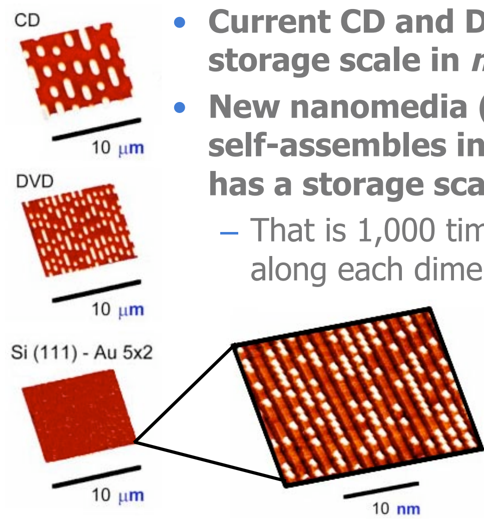


Nano solar cell: Inorganic nanorods embedded in semiconducting polymer, sandwiched between two electrodes

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

NanoSense 7

Technology: A DVD That Could Hold a Million Movies



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

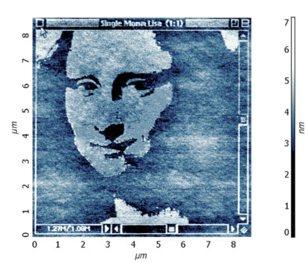
…or 1,000,000 times greater storage density in total!

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

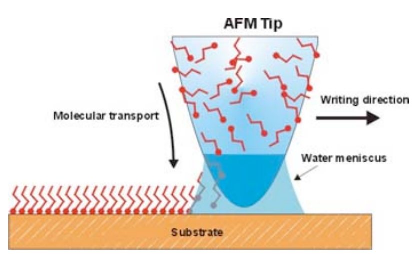
NanoSense 8

Technology: Building Smaller Devices and Chips

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



Mona Lisa, 8 microns tall, created by AFM nanolithography



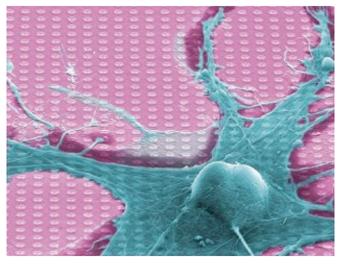
Transporting molecules to a surface by dip-pen nanolithography

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

NanoSense 9

Health Care: Nerve Tissue Talking to Computers

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



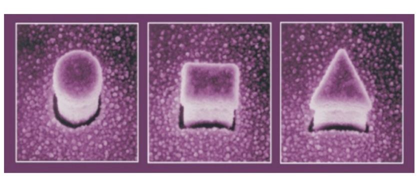
Snail neuron grown on a chip that records the neuron's activity

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

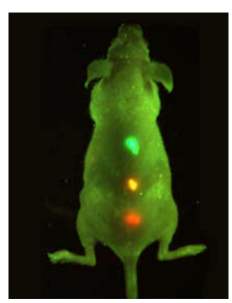
NanoSense 10

Health Care: Detecting Diseases Earlier

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



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



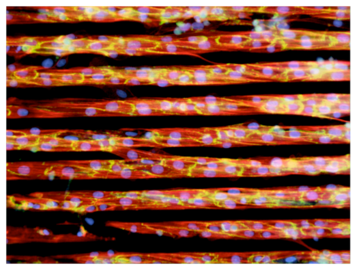
Early tumor detection, studied in mice

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

NanoSense 11

Health Care: Growing Tissue to Repair Hearts

- **Nanofibers help heart muscle grow in the lab**
  - Filaments ‘instruct’ muscle to grow in orderly way
  - Before that, fibers grew in random directions



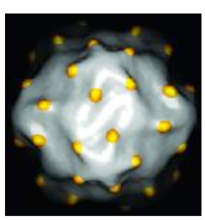
Cardiac tissue grown with the help of nanofiber filaments

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

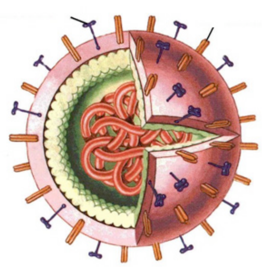
NanoSense 12

Health Care: Preventing Viruses from Infecting Us

- **Nanocoatings over proteins on viruses**
  - Could stop viruses from binding to cells
  - Never get another cold or flu?



Gold tethered to the protein shell of a virus



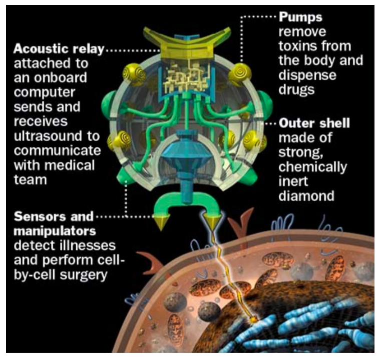
Influenza virus: Note proteins on outside that bind to cells

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

NanoSense 13

Health Care: Making Repairs to the Body

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



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

NanoSense 14

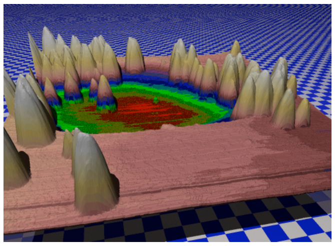
Pause to Consider

How delicate are nanoscale-sized objects?

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

Nanodevices Are Sensitive!

- **Radiation particles can cause fatal defects**
  - Development requires very clean environments
  - Redundant copies compensate for high defect rate



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

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

Potential Risks of Nanotechnology

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

Summary: Science at the Nanoscale

- **An emerging, interdisciplinary science**
  - Integrates chemistry, physics, biology, materials engineering, earth science, and computer science
- **The power to collect data and manipulate particles at such a tiny scale will lead to**
  - New areas of research and technology design
  - Better understanding of matter and interactions
  - New ways to tackle important problems in healthcare, energy, the environment, and technology
  - A few practical applications now, but most are years or decades away

Applications of Nanoscience Slides: Teacher Notes

Overview

This series of slides introduces students to some of the areas thought to have great potential for impact on our lives through nanotechnology innovations. Example applications and references for further information are provided. *Don't feel that you need to show all of these slides*. Show the ones that you think will most interest and reach your particular students.

Slide 1: Applications of Nanoscience

Explain to students that you're going to present several examples of how new innovations in nanotechnology might impact our lives.

Slide 2: Potential Impact of Nanotechnology

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

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

References:

- Nanotechnology now – Current uses: http://www.nanotech-now.com/current-uses.htm
- Nanoscale Science and Engineering Center: http://www.mos.org/cst/section/2.html
- Book: "The Next Big Thing Is Really Small: How Nanotechnology Will Change The Future Of Your Business" by Jack Uldrich and Deb Newberry (2003)

Slide 3: Materials: Stain Resistant Clothes

Manufacturers are embedding fine-spun fibers into fabric to confer stain resistance on khaki pants and other products. These "nanowhiskers" act like peach fuzz and create a cushion of air around the fabric so that liquids bead up and roll off. Each nanowhisker is only ten nanometers long, made of a few atoms of carbon. To attach these whiskers to cotton, the cotton is immersed in a tank of water full of billions of nanowhiskers. Next, as the fabric is heated and water evaporates, the nanowhiskers form a chemical bond with cotton fibers, attaching themselves permanently. The whiskers are so tiny that if the cotton fiber were the size of a tree trunk, the whiskers would look like fuzz on its bark.

Nano-resistant fabric created by NanoTex is already available in clothing available in stores like Eddie Bauer, The Gap, and Old Navy. This innovation will impact not only khaki wearers, but also dry cleaners who will find their business declining, and detergent makers who will find less of their project moving off the shelf.

References:

- Fancy pants: http://www.sciencentral.com/articles/view.php3?article_id=218391840&cat=3_5
- NanoTex lab activity: http://mrsec.wisc.edu/Edetc/IPSE/educators/activities/nanoTex.html

Slide 4: Materials: Paint That Doesn't Chip

Nanopaints are ceramic based coatings that make the paint a lot more durable and resistant to rock chips and scratches. In addition to holding up better to weathering, nanopaints have richer and brighter colors than traditional pigments. In the future, nanopaints may also even change color

References:

- Mercedes-Benz Nano Paint (3 page article on benefits, material, and paint process): http://www.auto123.com/en/info/news/news,view.spy?artid=21942&pg=1

Slide 5: Environment: Paint That Cleans Air

Chinese scientists have announced that they have invented nanotech-based coating material that acts as a permanent air purifier. If the coating proves to be effective at air cleaning, it will be gradually used on buildings to improve air quality. The core of the material is a titanium-dioxide-based compound developed using advanced nanotechnology. Exposed under sunlight, the substance can automatically decompose ingredients like formaldehyde that cause air pollution.

References:

- Paint to help clean and purify the air: http://english.eastday.com/eastday/englishedition/metro/userobject1ai710823.html

Slide 6: Environment: Nano Solar Cells

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

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

References:

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

Slide 7: Technology: A DVD That Could Hold a Million Movies

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

References:

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

Slide 8: Technology: Building Smaller Devices and Chips

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

References:

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

Slide 9: Health Care: Nerve Tissue Talking to Computers

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

References:

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

Slide 10: Health Care: Detecting Diseases Earlier

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

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

References:

- Quantum dots introduction: http://vortex.tn.tudelft.nl/grkouwen/qdotsite.html
- Lawrence Livermore Labs work in quantum dots: http://www.llnl.gov/str/Lee.html

- Quantum dots light up prostate cancer: http://www.whitaker.org/news/nie2.html

Slide 11: Health Care: Growing Tissue to Repair Hearts

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

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

References:

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

Slide 12: Health Care: Preventing Viruses from Infecting Us

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

References

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

Slide 13: Health Care: Making Repairs to the Body

The image on this slide depicts what one nanoscientist from the Foresight Institute imagines might be possible one day in the far future. It shows how a nanorobot could potentially interact with human cells. When people hear of nanotechnology from science fiction, this is often the form that it takes. But we may not know for decades whether such a probe is even possible. But if they are developed someday, they could be used to maintain and protect the human body against pathogens. For example, they could (1) be used to cure skin diseases (embedded in a cream, they could remove dead skin and excess oils, apply missing oils), (2) be added to mouthwash to destroy bacteria and lift plaque from the teeth to be rinsed away, (3) augment the immune system by finding and disabling unwanted bacteria and viruses, or (4) nibble away at plaque deposits in blood vessels, widening them to prevent heart attacks.

References:

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

Slide 14: Pause to Consider

The next 2 slides focus on the delicate nature of nanosized objects, the potential risks of nanotechnology to humans and the environment, and the need study the risks and regulate the development of products that contain nanoparticles.

Slide 15: Nanodevices Are Sensitive!

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

References:

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

Slide 16: Potential Risks of Nanotechnology

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

References:

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

Slide 17: Summary: Science at the Nanoscale

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

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

What's New Nanocat? Poster Session: Teacher Instructions & Rubric

Summary

Students will work in pairs to create a poster that compares a current technology with a related, new nanotechnology application. A list of applications (including references) to choose from will be provided to the students. The list is based on applications that have been mentioned or discussed in class or in associated readings (e.g., nanotubes as stronger tethers, nano solar cells as omnipresent collectors, stain-resistant nanopants).

The student will assume the role of a scientist working on the new nanotechnology application, and explain the proposed usage of the new technology in a poster session. The student will produce a poster showing a current technology and how it is used; a new, related nanotechnology and how it is proposed to be used; how the new nanotechnology works; and how the new nanotechnology will help improve understanding or solve a problem.

The posters will be displayed in class and the students will explain the technology by explaining the poster. This could be done in a science fair type arrangement or in class as a presentation. The presentation must include diagrams along with written descriptions to help someone gain a better understanding of the science. It can also optionally include animations.

Time Frame: 2-3 hours to create posters, 1 hour for poster session

Criteria for Evaluation

The poster will be graded based on a rubric. The student's discussion and answers to questions during the poster session will influence the grade. The students must demonstrate understanding of the technology s/he is explaining.

Relevant Learning Goals

- Nanoscience is an emerging science that could vastly change our understanding of matter and lead to new questions and answers in many areas, including health care, the environment, and technology.
- Nanotechnology focuses on manipulating matter at the nanoscale to create structures that have novel properties or functions.

Required Resources

- List of applications from which students can choose their poster topic.
- Access to the Web to research the technologies, find relevant diagrams, etc.
- Optional use of ChemSense to create diagrams or animations to illustrate how the technologies work
- Optional access to PowerPoint or other slide creation tool for creating poster pages
- If posters are to be displayed in the classroom, access to posterboard, paper, and printer, and glue or tape are required.

Rubric for NanoCat Poster Evaluation

	Novice (1) Absent, inaccurate, or confused	Apprentice (2) Partially developed	Skilled (3) Adequately developed	Masterful (4) Fully developed
Written explan-ations	Shows little understanding or major misunderstanding of ideas or processes. Concepts, data, and arguments are inadequate. Many grammatical errors.	Shows limited understanding or misunderstanding of key ideas. Concepts, data, and arguments are simple or somewhat inadequate. Some grammar errors.	Shows a solid understanding of ideas, no misunderstanding of key ideas. Concepts, data, arguments are appropriate. Grammar is mostly correct.	Shows clear, complete, and sophisticated understanding of ideas, advanced beyond the grasp usually found at this age. Easy to read, with correct grammar.
Graphic explan-ations	Shows little understanding of processes, or inadequate for addressing the application.	Shows limited understanding of ideas. Graphics are crude, simple, or reveal a key misunderstanding.	Shows solid understanding. Graphics show no misunderstanding of key ideas, are not overly simple.	Shows clear, complete, and sophisticated understanding of ideas and processes.
Accuracy and Research	Misunderstanding of nanoscience is evident in inaccurate explanations or science-fiction-like ideas presented as facts. Demonstrates little or no research.	Limited understanding is evident by some inaccurate or simple explanations, or futuristic ideas confused with fact. Demonstrates average research.	Shows solid understanding with clear explanations with sound scientific basis, no clear inaccuracies. Demonstrates solid research.	Shows sophisticated understanding based on current facts and scientific theory, and futuristic ideas presented as such. Demonstrates extensive research.
Attract-iveness	Distractingly messy or bad design.	Somewhat organized, acceptable design, but messy.	Solid organization, with good design, layout, and neatness.	Sophisticated presentation that is well organized and neat, with good design and layout.
Attribu-tion	Diagrams and text do not have any source citations.	More than two diagrams and text do not have source citations.	All but one or two diagrams and text have source citations.	All text and borrowed diagrams have source citations.
Oral Team Present-ation	Most members did not participate, communication was unclear, hard to hear, little eye contact, answered few questions.	Few members participated, communication was somewhat unclear, answered half of audience questions well.	Most members participated, communicated clearly, answered most audience questions reasonably well.	All team members participated, communicated clearly, kept eye contact, and answered audience questions well.

Lesson 5: Applications of Nanoscience

Student Materials

Contents

What's New Nanocat? Poster Session: Student Directions

Overview

When scientists want to share their findings and proposals with other scientists, they often do it at a national meeting with scientists who have the same interests. They often share ideas at what is called a *poster session*. The scientists come to the meeting with a poster that explains in *text and graphics* what their findings or proposal is all about. The poster is usually either a rolled up paper about 4 feet long and 2.5 feet wide, or a set of 8-12 normal (letter size) printed pages that they tack up on a board. They stand near the poster and as others walk by, they discuss their work with the other scientists and answer questions.

Your Assignment

You will assume the role of a prominent nanoscientist working on a new nanotechnology application, and explain the proposed usage of the new technology to replace a current technology in a poster session. You will be given a list of nanotechnology applications (based on what we have discussed in class) from which you can choose, or you can prepare a poster on an application that is not on the list if your teacher approves it. The posters will be displayed in class and you will explain the technology by explaining the poster. Your classmates will assess your poster, and you will assess their posters, using the Poster Feedback Sheet.

Your poster must include the following:

1. A written description of the current technology and how it is used, and how it works.
2. At least one picture or diagram that helps illustrate how the current technology works.
3. A written description of the new, related nanotechnology, how it is proposed to be used, and how it works.
4. At least one picture or diagram that helps illustrate how the new nanotechnology works.
5. A written description of the implications of the new nanotechnology: how it will help improve understanding, solve a problem, and possible ethical or societal issues.

At the poster session, be prepared to discuss the applications and answer questions, so that someone visiting the poster will walk away with a good understanding of the science.

Grading

To receive full credit,

1. Your poster must include all of the elements mentioned above.
2. Your written descriptions and diagrams must have a sound scientific basis.
3. Your design should be neat and have an attractive layout.
4. All text and borrowed diagrams must have source citations.
5. Your oral explanation must be clear and understandable, all team members must participate, and you should be able to answer questions about the poster and how you created it.

What's New Nanocat? Poster Session: Student Topic List

Stain Resistant Clothes

Manufacturers are embedding fine-spun fibers into fabric to confer stain resistance on khaki pants and other products. These "nanowhiskers" act like peach fuzz and create a cushion of air around the fabric so that liquids bead up and roll off. Each nanowhisker is only ten nanometers long, made of a few atoms of carbon. To attach these whiskers to cotton, the cotton is immersed in a tank of water full of billions of nanowhiskers. Next, as the fabric is heated and water evaporates, the nanowhiskers form a chemical bond with cotton fibers, attaching themselves permanently. The whiskers are so tiny that if a cotton fiber were the size of a tree trunk, the whiskers would look like fuzz on its bark. Nano-resistant fabric created by NanoTex is already available in clothing available at stores like Eddie Bauer, The Gap, and Old Navy. This innovation will impact not only khaki wearers, but also dry cleaners who will find their business declining, and detergent makers who will find less of their project moving off the shelf. Nanoparticles (e.g., of silver) could also be introduced to destroy microbes and create odor-resistant cloths.

More information:

- Fancy pants: http://www.sciencentral.com/articles/view.php3?article_id=218391840&cat=3_5
- Nano fiber finishing: http://www.textileinfo.com/en/tech/nanotex/page02.html
- Odor-resistant products: http://www.physorg.com/news1373.html

Paint That Resists Chipping

On cars, special nanopaints that hold up better to weathering, are more resistant to chipping and have richer and brighter colors than traditional pigments. The paints contain tiny ceramic particles added to a liquid clearcoat. The particles link and create a very dense and smoothly structured network that provides a protective layer.

More information:

- Mercedes-Benz Nano Paint (3 page article on benefits, material, and paint process): http://www.auto123.com/en/info/news/news,view.spy?artid=21942&pg=1
- Nanotechnology improves paint gloss: http://www.canadiandriver.com/articles/jk/040407.htm
- Mercedes tougher, shinier nanopaint: http://www.supanet.com/motoring/testdrives/news/40923/

Paint That Cleans the Air

Chinese scientists have announced that they have even invented nanotech-based coating material that acts as a permanent air purifier. If the coating proves to be effective at air cleaning, it will be gradually used on buildings across Shanghai in order to improve the city's air quality. The core of the material is a titanic-oxide-based compound that comprises particles at nanoscale achieved by advanced nanotechnology. Exposed under sunlight, the substance can automatically decompose the major ingredients that cause air pollution such as formaldehyde and nitride.

More information:

- Paint to help clean and purify the air: http://english.eastday.com/eastday/englishedition/metro/userobject1ai710823.html
- New pollution paint will clean the air: http://www.edie.net/news/news_story.asp?id=8025&channel=0
- Smog-busting paint: http://www.ananova.com/news/story/sm_862568.html?menu=news.latestheadlines

Painting On Solar Cells

Enough energy from the sun hits the earth every day to completely meet all energy needs on the planet, if only it could be harnessed. Doing so could wean us off of fossil fuels like oil and provide a clean energy alternative. But currently, solar-power technologies cost as much as 10 times the price of fossil fuel generation. Chemists at U.C. Berkeley are developing nanotechnology to produce a photovoltaic material that can be spread like plastic wrap or paint. These nano solar cells could be integrated with other building materials, and offer the promise of cheap production costs that could finally make solar power a widely used electricity alternative. Current approaches embed nanorods (bar-shaped semiconducting inorganic crystals) in a thin sheet (200 nanometers deep) of electrically conductive polymer. Thin layers of an electrode sandwich these nanorod-polymer composite sheets. When sunlight hits the sheets, they absorb photons, exciting electrons in the polymer and the nanorods, which make up 90 percent of the composite. The result is a useful current that is carried away by the electrodes. Eventually, nanorod solar cells could be rolled out, ink-jet printed, or even painted onto surfaces, so that even a billboard on a bus could be a solar collector.

More information:

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

High Density Storage Media

New nanomedia could have a storage density that is a million times higher that current CDs and DVDs. Nano storage applications currently in development use a variety of methods, including self-assembly.

More information:

- Franz J. Himpsel's web site: http://uw.physics.wisc.edu/~himpsel/nano.html

- Nanoscale memory: http://uw.physics.wisc.edu/~himpsel/memory.html
- Nanoscale memory developed at ASU: http://www.asu.edu/feature/nanoscale.html
- IBM's Millipede project demonstrates trillion-bit data storage density: http://domino.research.ibm.com/comm/pr.nsf/pages/news.20020611_millipede.html
- IBM puts new spin on nano-storage: http://news.zdnet.com/2100-9584_22-934825.html
- Nanoscale memory builds itself: http://www.betterhumans.com/News/news.aspx?articleID=2003-12-09-5

Smaller Devices and Chips

A technique called nanolithography enables us to create much smaller devices than current approaches. For example, dip pen nanolithography is a 'direct write' technique that uses an AFM to create patterns and to duplicate images. "Ink" is laid down atom by atom on a surface, through a solvent—often water.

More information:

- AFM Oxidation nanolithography http://www.ntmdt.ru/SPM-Techniques/Principles/Lithographies/AFM_Oxidation_Lithography_mode37.html
- Dip pen nanolithography (DPN): http://www.chem.northwestern.edu/~mkngrp/dpn.htm
- Improved DPN through thermal dip pen nanolithography: http://www.voyle.net/Nano%20Research%20200/research00110%20.htm

Hybrid Neuro-Electronic Networks

Researchers are studying the electrical interfacing of semiconductors with living cells—in particular, neurons—to build hybrid neuro-electronic networks. Cellular processes are coupled to microelectronic devices through the direct contact of cell membranes and semiconductor chips. For example, electrical interfacing of individual nerve cells and semiconductor microstructures allow nerve tissue to directly communicate their impulses to computer chips. This research is directed (1) to reveal the structure and dynamics of the cell-semiconductor interface and (2) to build up hybrid neuro-electronic networks. Other researchers have built a cyborg, a half-living, half-robot creature that connects the brain of an eel-like fish to a computer and is capable of moving towards lights. Such research explores the new world at the interface of the electronics in inorganic solids and the ionics in living cells, providing the basis for future applications in medical prosthetics, biosensorics, brain research and neurocomputation. For example, neuro-electronic networks could lead implants that can restore sight.

More information:

- Nanopicture of the day from Peter Fromherz: http://www.nanopicoftheday.org/2003Pics/Neuroelectronic%20Interface.htm
- Max Planck research: http://www.biochem.mpg.de/mnphys/
- Lamprey cyborg: http://www.sciencenews.org/articles/20001111/fob4.asp

Detecting Disease with Quantum Dots

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

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

More information:

- Quantum dots introduction: http://vortex.tn.tudelft.nl/grkouwen/qdotsite.html
- Lawrence Livermore Labs work in quantum dots: http://www.llnl.gov/str/Lee.html
- Quantum dots light up prostate cancer: http://www.whitaker.org/news/nie2.html
- Quantum Dots. Cientifica White Paper. http://nanotechweb.org/dl/wp/quantum_dots_WP.pdf

Growing Tissue to Repair Hearts

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

More information:

- University of Washington cardiac muscle work: http://www.washington.edu/admin/finmgmt/annrpt/mcdevitt.htm
- The heart of tissue engineering: http://www.coe.berkeley.edu/labnotes/1202/healy.html

Preventing Viruses from Infecting Us

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

More information:

- Virus nanoblocks http://pubs.acs.org/cen/topstory/8005/8005notw2.html
- Nanotechnology could block viruses from entering cells: http://www.betterhumans.com/Errors/index.aspx?aspxerrorpath=/Nanotechnology_Could_Block_Viruses_from_Entering_Cells.Article.2003-03-20-1.aspx

Nanobots Making Repairs to the Body

Nanobots are decades off, but if they are developed someday, they could be used to maintain and protect the human body against pathogens. For example, they could (1) be used to cure skin diseases (embedded in a cream, they could remove dead skin and excess oils, apply missing oils), (2) be added to mouthwash to destroy bacteria and lift plaque or tartar from the teeth to be rinsed away, (3) augment the immune system by finding and disabling unwanted bacteria and viruses, or (4) nibble away at plaque deposits in blood vessels, widening them to prevent heart attacks.

More information:

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

Drug Delivery Systems

Nanotubes and buckyballs could serve as drug delivery systems. Researchers have attached florescent markers and proteins to nanotubes and mixed them with living cells. They can see (from the florescent marker) that the nanotubes enter the cell, and could "deliver" the protein inside the cell. The nanotubes don't seem toxic to the cell, so far, but lots more research to be done. Similarly, investigators anticipated that buckyball or fullerene-related structures could serve as "cages" for small drug molecules.

More information

- Tiny weapons with giant potential: http://www.mult-sclerosis.org/news/Jul2002/NanobombsDeliveringDrugs.html
- Amino groups link up with carbon nanotubes: http://nanotechweb.org/articles/news/2/3/1/1
- Buckymedicine: http://www.sciencenews.org/articles/20020713/bob10.asp

Self-Cleaning Surfaces

Self-cleaning surfaces (e.g., windows, mirrors, toilets) could be made with bioactive coatings. Researchers have already developed water-repellent surfaces that could lead to self-cleaning glass. This surface mimics the surface of the water lily, which is waxy and covered with tiny bumps, so water rolls off. There are spray coatings that currently exist that make glass self-cleaning, but these coatings wear off. Nanotechnology would build this new surface into the surface of the window, so it would work for the lifetime of the window.

More information:

- Bumpy glass could lead to self-cleaning windows: http://www.voyle.net/Future%20Technology%202005/Future%202005-0006.htm
- Yes, it's true: Windows that clean themselves: http://www.clarkpublicutilities.com/Residential/TheEnergyAdviser/Archives2004/04_10_17
- ABC News: Scientists develop self-cleaning windows: http://abcnews.go.com/Technology/DyeHard/story?id=440893&page=1

Food Storage and Manufacturing

Nanocomposites for plastic film coatings used in food packaging could detect or even prevent contamination in food or food packaging. This could enable wider distribution of food products to remote areas in less industrialized countries.

More information:

- Food manufacture: A mini revolution: http://www.foodmanufacture.co.uk/news/fullstory.php/aid/472/A_mini_revolution.html
- Coating process could revolutionize food packaging: http://www.bakeryandsnacks.com/news/news-NG.asp?id=50325
- Hungry for nano: The fruits of nanotechnology could transform the food industry: http://www.findarticles.com/p/articles/mi_m1200/is_13_166/ai_n6366589

Water Treatment

Nanotechnology could lead to advanced water-filtering membranes that could purify even the worst of wastewater. Only about 1 percent of the water in the world is usable (97 percent is saltwater, and two-thirds of the remaining fresh water rest is ice). With the world population expected to double in 40 years, over half the world population could face a very serious water shortage in that time. Even now, 10,000 to 60,000 people die every day because of diseases caused by bad water. Advanced nanomembranes could be used for water purification, desalination, and detoxification, nanosensors could detect contaminants and pathogens, and nanoparticles could degrade water pollutants and make salt water and even sewage water easily converted into usable, drinkable water.

More information:

- Nano world: Water, water everywhere nano: http://www.wpherald.com/storyview.php?StoryID=20050318-112217-1110r
- Nanowater: http://www.nanowater.org/nano.htm
- Wired News: Water filters rely on nanotech: http://www.wired.com/news/technology/0,1282,65287,00.html

Health Monitoring

Several nano-devices are being developed to keep track of daily changes in patients' glucose and cholesterol levels, aiding in the monitoring and management of diabetes and high cholesterol for better health. For example, some researchers have created coated nanotubes in a way that will fluoresce in the presence of glucose. Inserted into human tissue, these nanotubes can be excited with a laser pointer and provide real-time monitoring of blood glucose level. No more discomfort from needles, pricking, or drawing blood!

More information:

- Selective coatings create biological sensors from carbon nanotubes: http://www.voyle.net/Nano%20Research%20200/research00176.htm
- Nano-sensor to monitor glucose levels in diabetics: http://www.123bharath.com/health-india-news/index.php?action=fullnews&id=44390
- Encapsulated Carbon Nanotubes for Implantable Biological Sensors to Monitor Blood Glucose Levels: http://www.azonano.com/news.asp?newsID=439
- Glowing sensor may allow artificial pancreas: http://www.betterhumans.com/News/news.aspx?articleID=2004-03-17-3

Clean Energy

Cars of the future may use nonpolluting hydrogen fuel cells. Today, hydrogen fuel is expensive to make, but with catalysts made from nanoclusters, it may be possible to generate hydrogen from water by photocatalytic reactions. Novel hydrogen storage systems could be based on carbon nanotubes and other lightweight nanomaterials, nanocatalysts could be used for hydrogen generation, and nanotubes could be used for energy transport.

More information:

- Sun and hydrogen to fuel future: http://news.bbc.co.uk/2/hi/science/nature/3536156.stm
- Nanotechnology could promote hydrogen economy: http://www.eurekalert.org/pub_releases/2005-03/rtsu-ncp032805.php
- USF working hard to make alternative fuels a reality: http://www.voyle.net/Nano%20Research/research00092%20.htm
- Our energy challenge: http://smalley.rice.edu/

Name___________________________________ Date______________________ Period ______

What's New Nanocat? Poster Session: Peer Feedback Form

1. What is the topic of the poster you are evaluating?

2. What are the names of the students who developed the poster you are evaluating?

3. The poster contained the following items:

A text description of a current technology and how it works.	True	False
A picture that helps illustrate how the current technology works.	True	False
A text description of a new, related nanotechnology and how it works.	True	False
A picture that helps illustrate how the new nanotechnology works.	True	False
A text description of the implications of the nanotechnology: how it will help improve understanding, solve a problem, and any possible societal issues.	True	False

4. How strongly do you agree with the following statements?

	Strongly Agree	Agree	Unsure	Disagree	Strongly Disagree
The poster is visually appealing.	1	2	3	4	5
The poster has a solid scientific basis.	1	2	3	4	5
The poster presenters communicated clearly and answered questions effectively.	1	2	3	4	5
Borrowed text and pictures have citations.	1	2	3	4	5

5. What was your favorite part of the poster?

6. Any additional comments or suggestions for the poster or poster presenters?

One-Day Introduction to Nanoscience

Teacher Materials

Contents

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

Lesson Plan: One-Day Introduction to Nanoscience

Orientation

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

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

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

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

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

Essential Questions (EQ)

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

(Numbers correspond to learning goals overview document)

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

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

Enduring Understandings (EU)

Students will understand:

(Numbers correspond to learning goals overview document)

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

Key Knowledge and Skills (KKS)

Students will be able to:

(Numbers correspond to learning goals overview document)

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

Prerequisite Knowledge and Skills

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

Related Standards

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

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

One Day Introduction to Nanoscience: Teacher Demonstration Instructions

Overview

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

Mesogold

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

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

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

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

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

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

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

How to Use It as a Demonstration

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

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

Questions to stimulate classroom discussion:

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

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

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

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

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

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

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

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

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

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

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

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

Where to Buy It

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

Ferrofluid

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

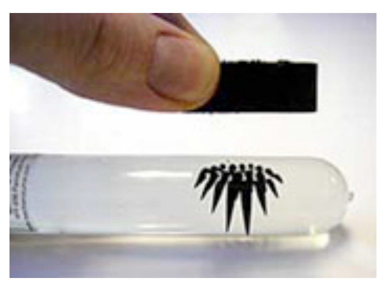


Figure 2. Ferrofluid from Educational Innovations, Inc. [2]

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

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

How to Use It as a Demonstration

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

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

Questions to stimulate discussion:

1. What is a liquid?

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

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

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

3. What does this distortion represent?

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

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

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

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

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

Where to Buy It

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

References

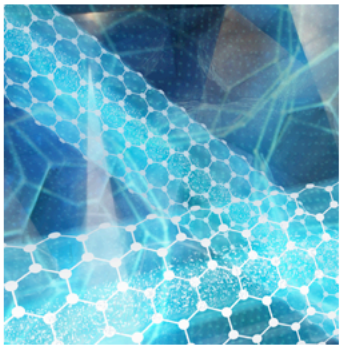
[1] http://www.purestcolloids.com/mesogold.htm

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

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

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

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



What's the Big Deal about Nanotechnology?

Science at the nanoscale involves a change of perspective!

NanoSense
the basic sense behind nanoscience

What is Nanoscale Science?

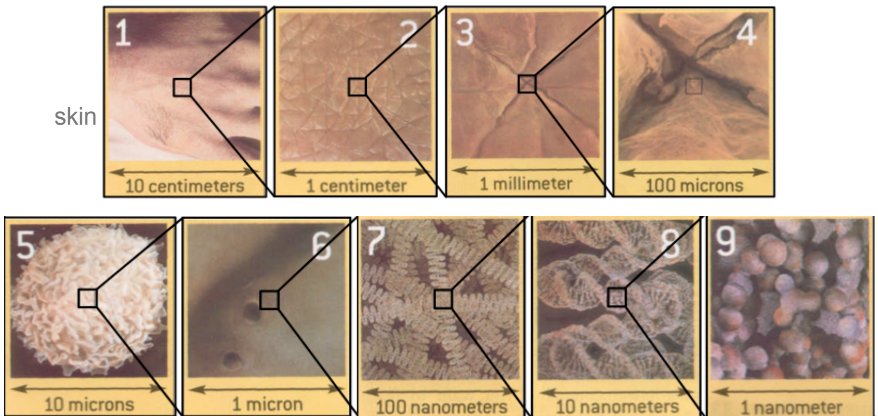
- **The study of objects and phenomena at a very small scale, roughly 1 to 100 nanometers (nm)**
  - 10 hydrogen atoms lined up measure about 1 nm
  - A grain of sand is 1 million nm, or 1 millimeter, wide
- **An emerging, interdisciplinary science involving**
  - Physics
  - Chemistry
  - Biology
 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

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

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

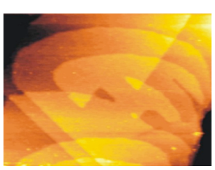
Potential Impacts

How might nanoscale science and engineering improve our lives?

NanoSense 6

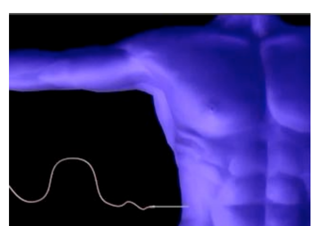
Innovations In Development or Under Investigation

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



Thin layers of gold are used in tiny medical devices

Carbon nanotubes can be used for H fuel storage

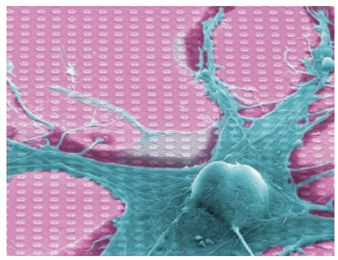


Possible entry point for nanomedical device

NanoSense 7

Health Care: Nerve Tissue Talking to Computers

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

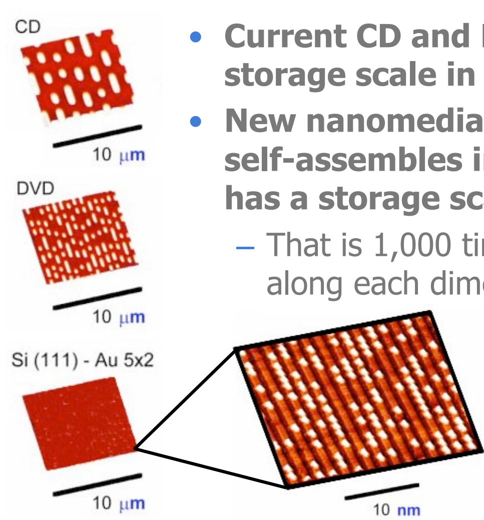


Snail neuron grown on a chip that records the neuron's activity

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

NanoSense 8

Technology: A DVD That Could Hold a Million Movies



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

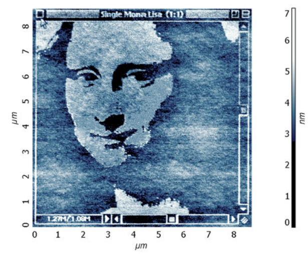
…or 1,000,000 times greater storage density in total!

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

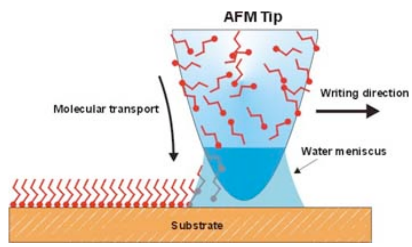
NanoSense 9

Technology: Building Smaller Devices and Chips

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



Mona Lisa, 8 microns tall, created by AFM nanolithography



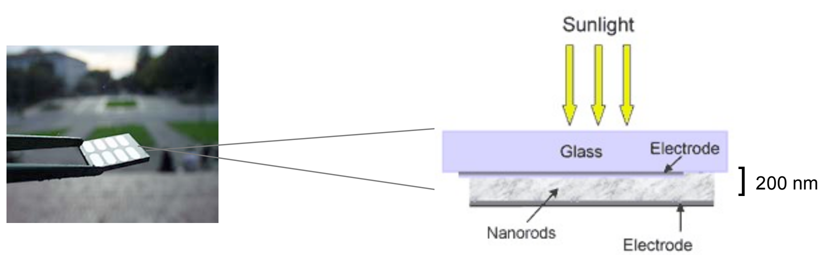
Transporting molecules to a surface by dip-pen nanolithography

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

NanoSense 10

Environment: Nano Solar Cells

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



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

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

NanoSense 11

So How Did We Get Here?

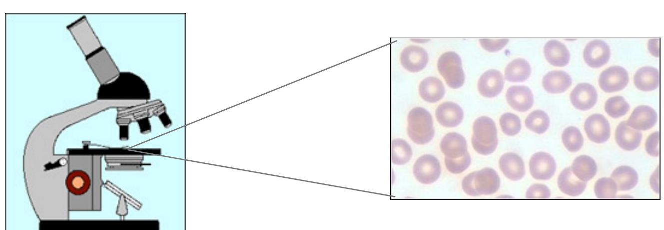
New Tools!

As tools change, what we can see and do changes

NanoSense 12

Using Light to See

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



Light microscope
(magnification up to 1000x)

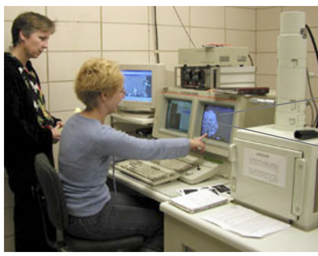
→ to see red blood cells
(400x)

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

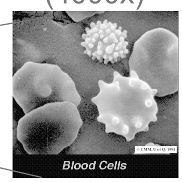
NanoSense 13

Using Electrons to See

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



(4000x)



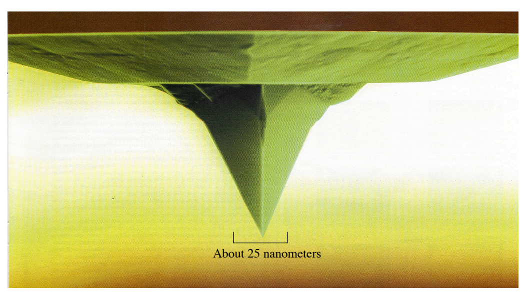
Greater resolution to see things like blood cells in greater detail

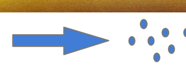
Sources: http://w w w .biotech.iastate.edu/facilities/BMF/images/SEMFaye1.jpg
http://cgee.hamline.edu/see/questions/dp_cycles/cycles_bloodcells_bw .jpg

NanoSense 14

Touching the Surface

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





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

Source: Scientific American, Sept. 2001

NanoSense 15

Size-Dependent Properties

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

How do properties change at the nanoscale?

NanoSense 16

Properties of a Material

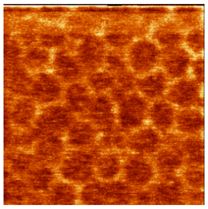
- **A property describes how a material acts under certain conditions**
- **Types of properties**
  - Optical (e.g. color, transparency)
  - Electrical (e.g. conductivity)
  - Physical (e.g. hardness, melting point)
  - Chemical (e.g. reactivity, reaction rates)
- **Properties are usually measured by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

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

Optical Properties Change: Color of Gold

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

"Bulk" gold looks yellow

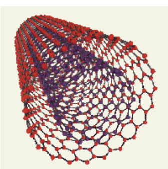


12 nanometer gold clusters of particles look red

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

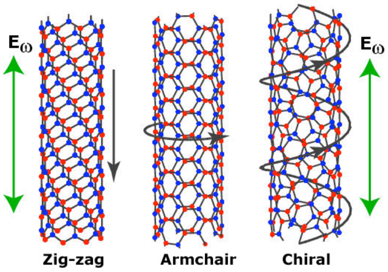
Electrical Properties Change: Conductivity of Nanotubes

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



Multi-walled

Electric current varies by tube structure



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

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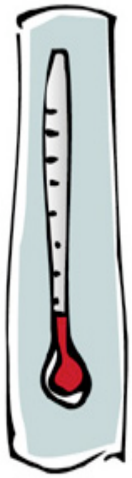
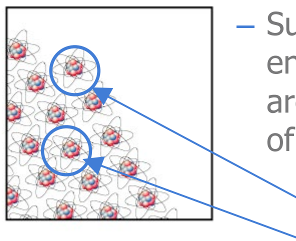
Physical Properties Change: Melting Point of a Substance



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



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

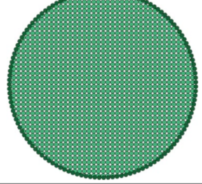
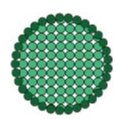
In contact with 3 atoms

In contact with 7 atoms

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

NanoSense 20

Physical Properties Example: Substance's Melting Point II

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

NanoSense 21

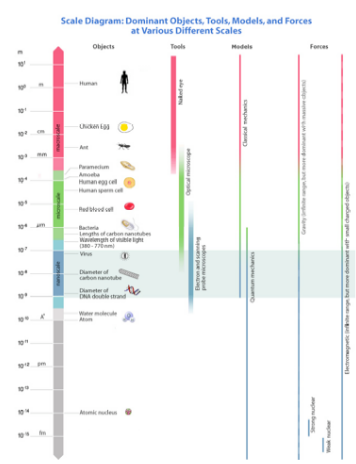
Size Dependant Properties

Why do properties change?

NanoSense 22

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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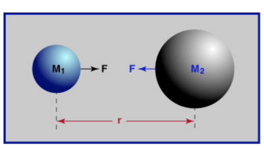
Scale Changes Everything II

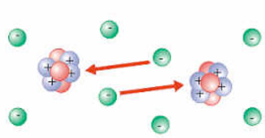
- **Four important ways in which nanoscale materials may differ from macroscale materials**
  - Gravitational forces become negligible and electromagnetic forces dominate
  - Quantum mechanics is the model used to describe motion and energy instead of the classical mechanics model
  - Greater surface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

NanoSense 24

Dominance of Electromagnetic Forces

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



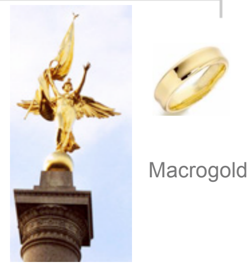


  - Gravitational force is a function of **mass** and distance and is weak between (low-mass) nanosized particles
  - Electromagnetic force is a function of **charge** and distance is not affected by mass, so it can be very strong even when we have nanosized particles
  - The electromagnetic force between 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

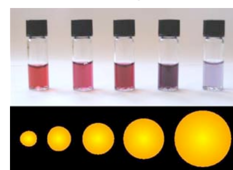
Quantum Effects

- **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

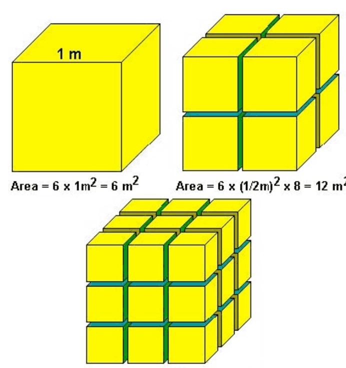
Nanogold



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;

Surface to Volume Ratio Increases

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



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

Random Molecular Motion is Significant

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

The random path of a dust particle in air

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

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

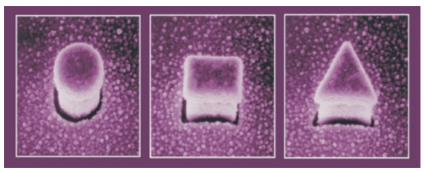
Nanotechnology is a Frontier in Modern-Day Science

What else could we possibly develop?

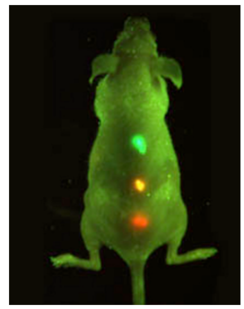
What other things are nanoengineers, researchers and scientists investigating?

Detecting Diseases Earlier

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



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



Early tumor detection, studied in mice

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

Growing Tissue to Repair Hearts

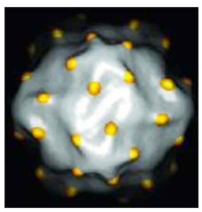
- **Growing cardiac muscle tissue is an area of current research**
  - Grown in the lab now, but the fibers grow in random directions
  - With the help of nanofiber filaments, it grows in an orderly way
- **Could be used to replace worn out or damaged heart tissue**

Cardiac tissue grown with the help of nanofiber filaments

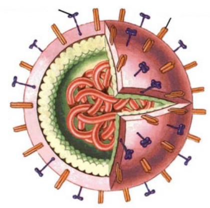
Source: http://www.washington.edu/admin/finmgmt/annrpt/mcdevitt.htm

Preventing Viruses from Infecting Us

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



Gold tethered to the protein shell of a virus

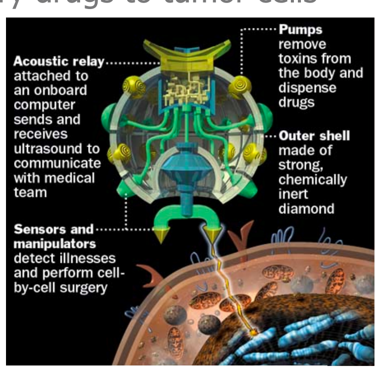


Influenza virus: Note proteins on outside that bind to cells

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

Making Repairs to the Body

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



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

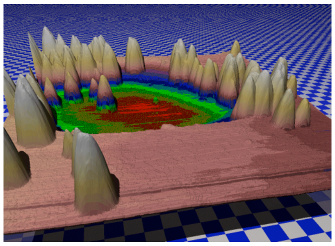
Pause to Consider

How delicate are nanoscale-sized objects?

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

Nanodevices Are Sensitive!

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



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

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

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Potential Risks of Nanotechnology

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

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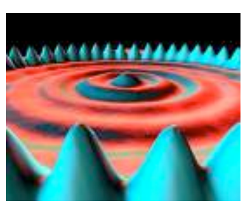
Summary: Science at the Nanoscale

- **An emerging, interdisciplinary science**

Materials Science
Earth Science
Physics
Chemistry

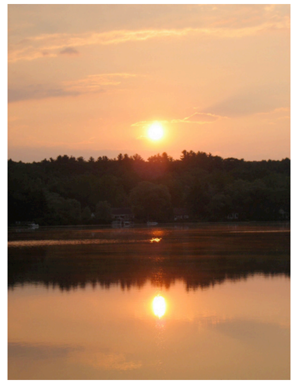


Biology
Engineering
Computer Science

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

Nanotechnology: A New Day

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



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

One Day Overview Introduction to Nanoscience Slides: Teacher Notes

Overview

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

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

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

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

Slide 2: What is Nanoscale Science?

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

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

Slide 3: How Big is a Nanometer?

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

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

Slide 4: Are you a Nanobit Curious?

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

Slide 5: Potential Impacts

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

Slide 6: Innovations In Development or Under Investigation

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

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

Slide 7: Health Care: Nerve Tissue Talking to Computers

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

References:

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

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

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

References:

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

Slide 9: Technology: Building Smaller Devices and Chips

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

References:

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

Slide 10: Environment: Nano Solar Cells

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

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

References:

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

Slide 11: So How Did We Get Here?

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

Slide 12: Using Light to See

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

Slide 13: Using Electrons to See

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

Slide 14: Touching the Surface

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

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

Slide 15: Size-Dependent Properties

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

Slide 16: Properties of a Material

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

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

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

Slide 17: Optical Properties Change: Color of Gold

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

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

Slide 18: Electrical Properties Example: Conductivity of Nanotubes

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

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

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

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

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

Slide 21: Size-Dependant Properties

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

Slide 22: Scale Changes Everything

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

Slide 23: Scale Changes Everything II

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

Slide 24: Dominance of Electromagnetic Forces

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

Slide 25: Quantum Effects

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

Slide 26: Surface to Volume Ratio Increases

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

Slide 27: Random Molecular Motion is Significant

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

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

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

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

Slide 29: Detecting Diseases Earlier

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

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

References:

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

Slide 30: Growing Tissue to Repair Hearts

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

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

References:

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

Slide 31: Preventing Viruses from Infecting Us

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

References

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

Slide 32: Making Repairs to the Body

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

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

References:

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

Slide 33: Pause to Consider

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

Slide 34: Nanodevices are Sensitive

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

References:

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

Slide 35: Potential Risks of Nanotechnology

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

References:

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

Slides 36: Summary: Science at the Nanoscale

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

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

Slides 37: Nanotechnology: A New Day

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