NanoSense

Teacher Materials

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CHAPTER 1 Size Matters-Teacher Materials

CHAPTER OUTLINE

1.1 INTRODUCTION TO NANOSCIENCE

1.1 Introduction to Nanoscience

Unit Overview

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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 #38; 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 #38; 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., #38; Robbins, M. (2005, June). The breakdown of continuum models for mechanical contacts. *Nature 435,* 929-932.

TABLE 1.1: 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

TABLE 1.2:

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

TABLE 1.2: (continued)

Lesson	Teaching Day	Main Activities and Materials	Learning Goals	Assessment	Homework
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

TABLE 1.2: (continued)

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	

TABLE 1.3:

What **enduring understandings (EU)** are desired? Students will understand:	What **essential questions (EQ)** will guide this unit and focus teaching and learning?	What **key knowledge and skills (KKS)** will students acquire as a result of this unit? Students will be able to:
• 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.	• How small is a nanometer, compared with a hair, a blood cell, a virus, or an atom?	• Describe, using the conventional language of science, the size of a nanometer. Make size comparisons of nanosized objects with other small objects.
• There are enormous scale differences in our universe, and at different scales, different forces dominate and different models better explain phenomena.	• Why are properties of nanoscale objects sometimes different than those of the same materials at the bulk scale?	• Explain why properties of nanoscale objects sometimes differ from those of the same materials at the bulk scale.

TABLE 1.3: (continued)

What **enduring understandings (EU)** are desired? Students will understand:	What **essential questions (EQ)** will guide this unit and focus teaching and learning?	What **key knowledge and skills (KKS)** will students acquire as a result of this unit? Students will be able to:
• Nanosized materials exhibit some size-dependent effects that are not observed in bulk materials.	• 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?	• Describe an application (or potential application) of nanoscience and it's possible effects on society.
• New tools for observing and manipulating matter increase our abilities to investigate and innovate.	• How do we see and move things that are very small?	• Compare a current technology solution with a related nanotechnology-enabled solution for the same problem.
	• Why do our scientific models change over time?	• Explain how an AFM and a STM work; give an example of their use.
	• What are some ways that the discovery of a new technology can impact our lives?	

Alignment of Unit Activities with Learning Goals

TABLE 1.4:

Learning Goals *Students will understand...*	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

TABLE 1.4: (continued)

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
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. Nano-sized 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...					

TABLE 1.4: (continued)

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
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

TABLE 1.5: 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

TABLE 1.5: (continued)

Unit Topic	Chapter Topic	Subtopic	Size Matters Lessons	Specific Materials
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, selfassembly)	• Lesson 1 (L1): Intro to Nanoscience	**Slides** • L1: 17-19 **Activity/Handout** • Reading: Intro to Nanoscience • Worksheet: Intro to Nanoscience

TABLE 1.5: (continued)

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 – 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

TABLE 1.5: (continued)

Unit Topic	Chapter Topic	Subtopic	Size Matters Lessons	Specific Materials
		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

TABLE 1.6: 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

TABLE 1.6: (continued)

Unit Topic	Chapter Topic	Subtopic	Size Matters Lessons	Specific Materials
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

TABLE 1.7: 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)

TABLE 1.8: (continued)

Unit Topic	Chapter Topic	Subtopic	Size Matters Lessons	Specific Materials

TABLE 1.8: 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

TABLE 1.8: (continued)

Unit Topic	Chapter Topic	Subtopic	Size Lessons	Matters	Specific Materials

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.
- 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 bloodbrain 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.

Introduction to Nanoscience

Teacher Lesson Plan

Contents

- Introduction to Nanoscience: Teacher Lesson Plan
- Introduction to Nanoscience: PowerPoint with Teacher Notes
- Introduction to Nanoscience Worksheet: Teacher Key

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 nano-sized 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

TABLE 1.9:

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	

TABLE 1.9: (continued)

Day	Activity	Time	Materials
	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

What is Nanoscale Science?

FIGURE 1.1

- 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 millionnm , or 1 millimeter , wide
- An emerging, interdisciplinary science involving
  - Physics
  - Chemistry
  - Biology
  - Engineering
  - Materials Science
  - Computer Science

How Big is a Nanometer?

- Consider a human hand

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

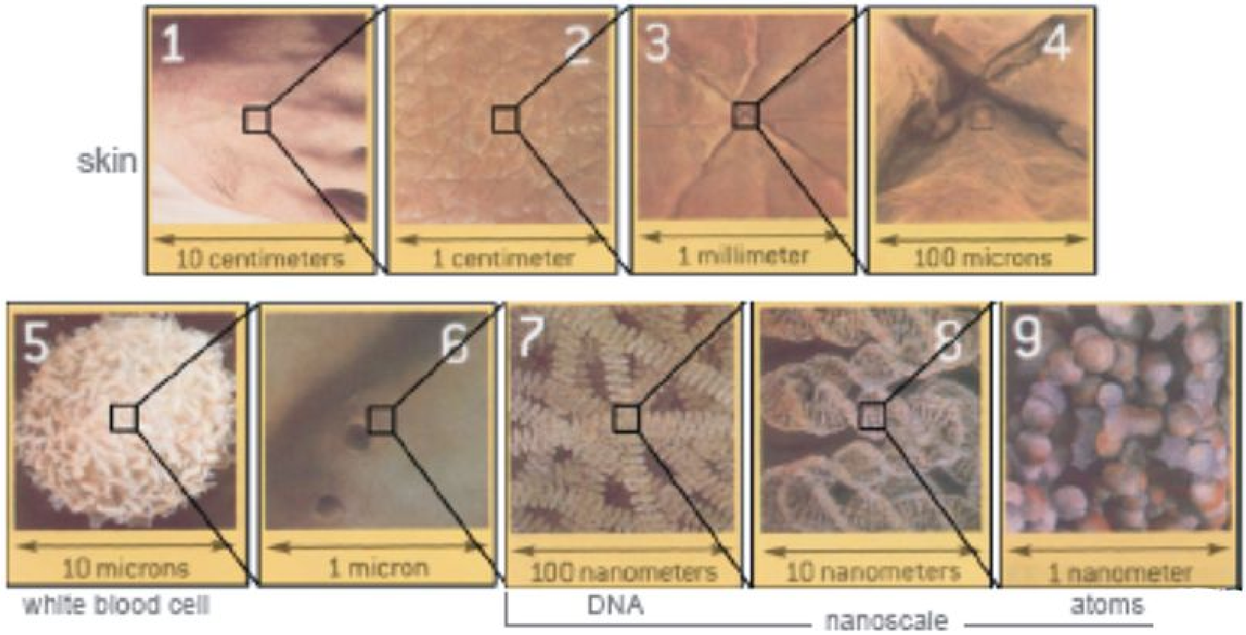


FIGURE 1.2

canseeanddochanges

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

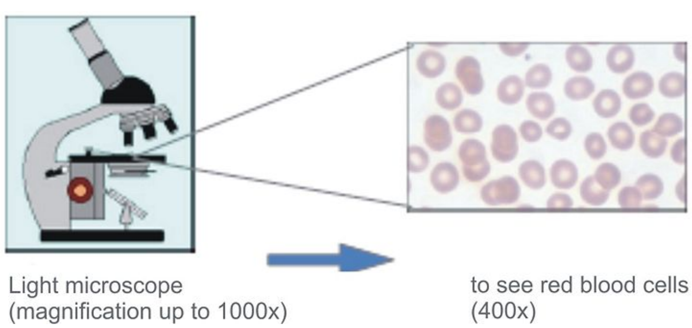


FIGURE 1.3

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

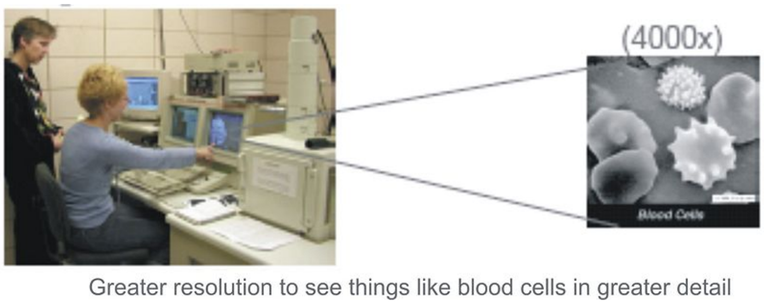


FIGURE 1.4

– Higher resolution due to small size of electrons

Touching the Surface

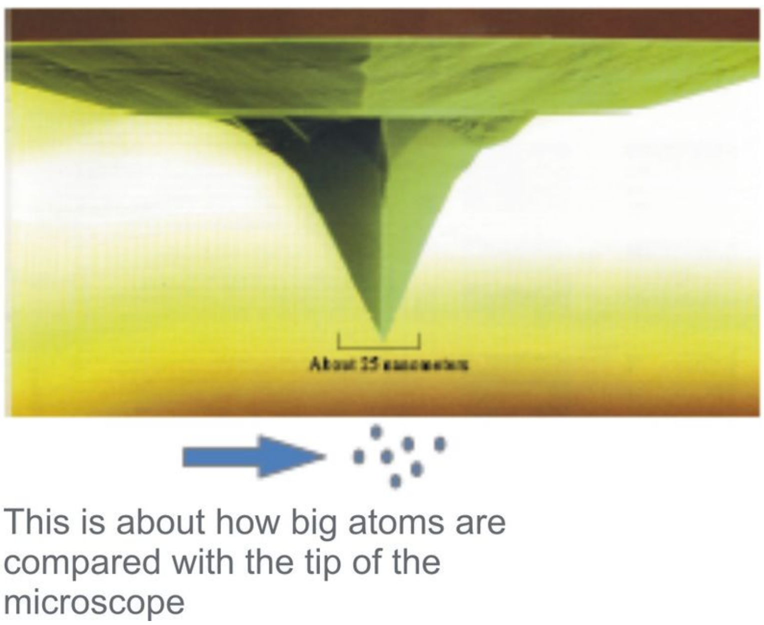


FIGURE 1.5

- 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!

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!

Is Gold Always "Gold"?

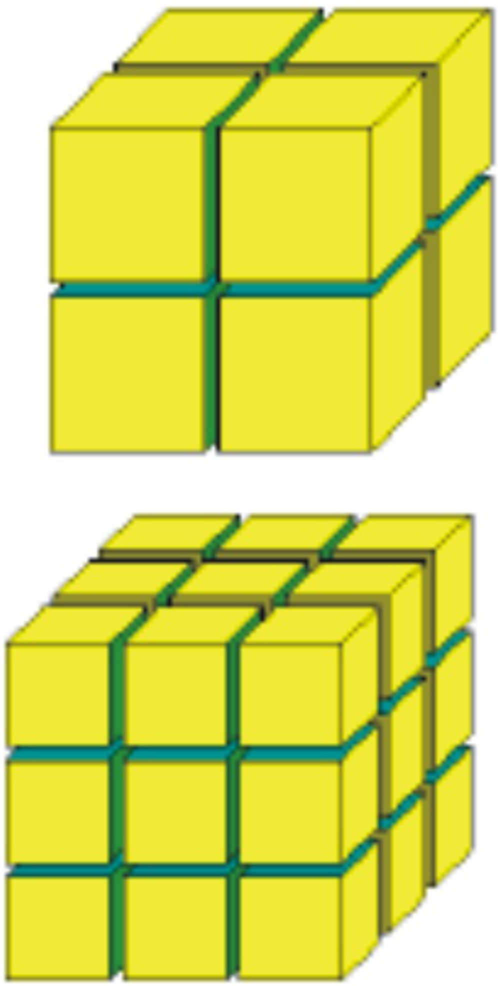


FIGURE 1.6

- 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"?

Nanogold

- Well... strange things happen at the small scale

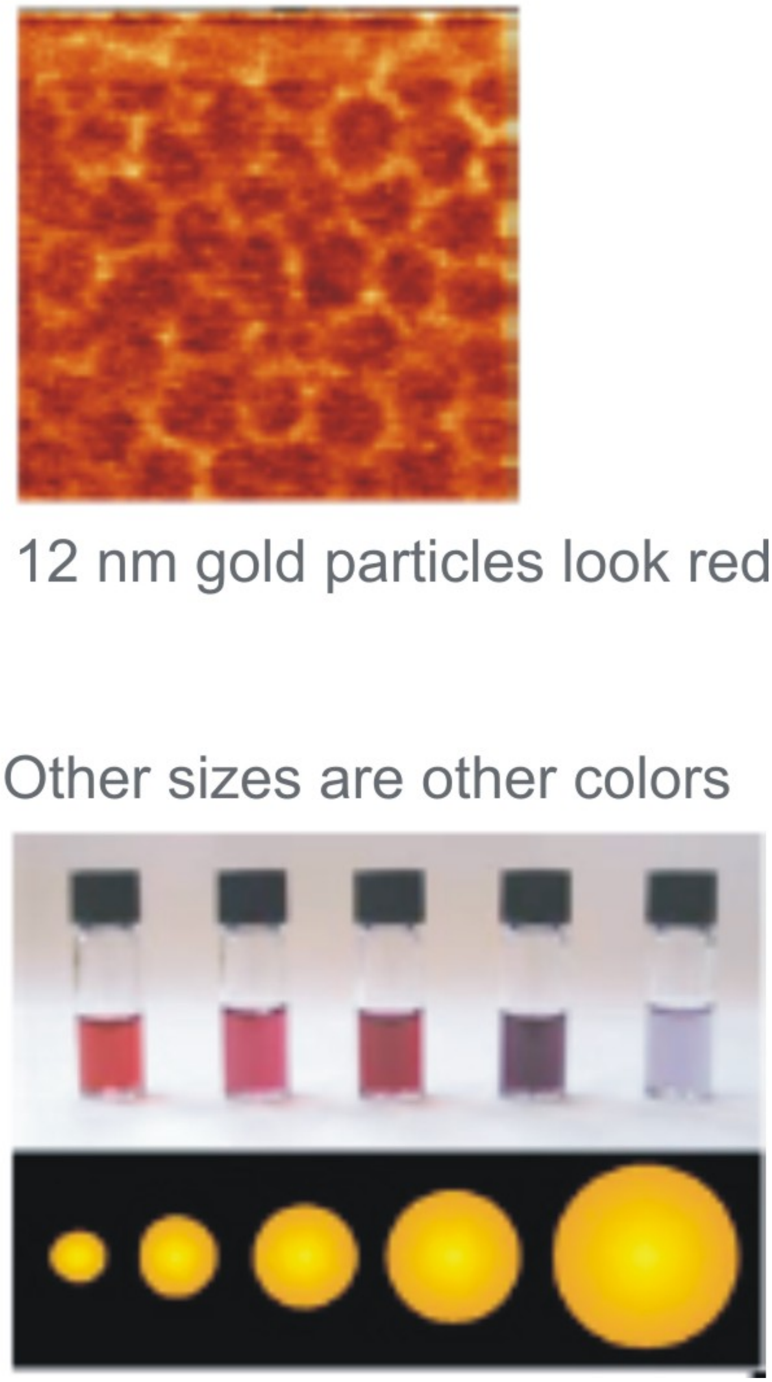


FIGURE 1.7

- 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

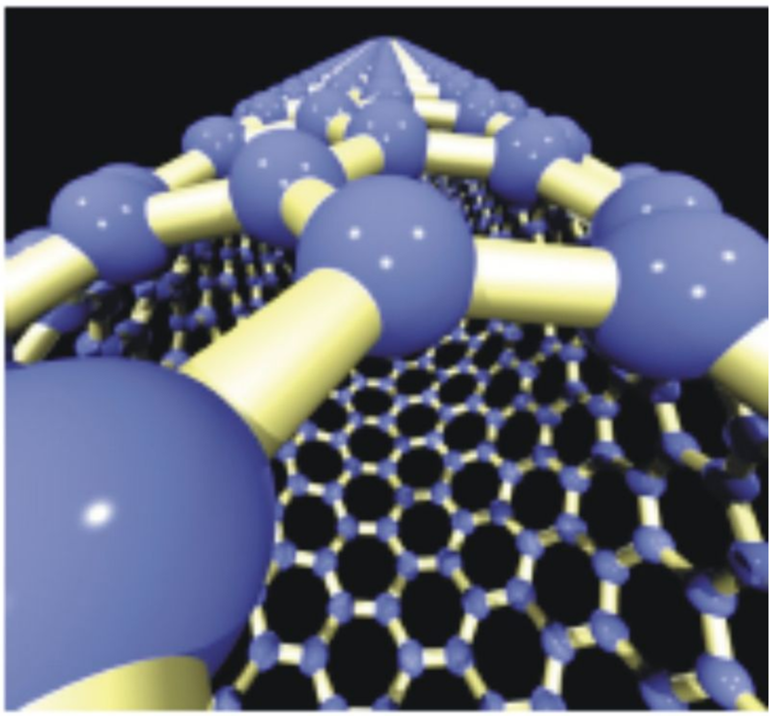
- Why?
  - Different thicknesses of materials reflect and absorb light differently

Nanostructures

What kind of nanostructures can we make?

What kind of nanostructures exist in nature?

Carbon Nanotubes



Model of a carbon nanotube

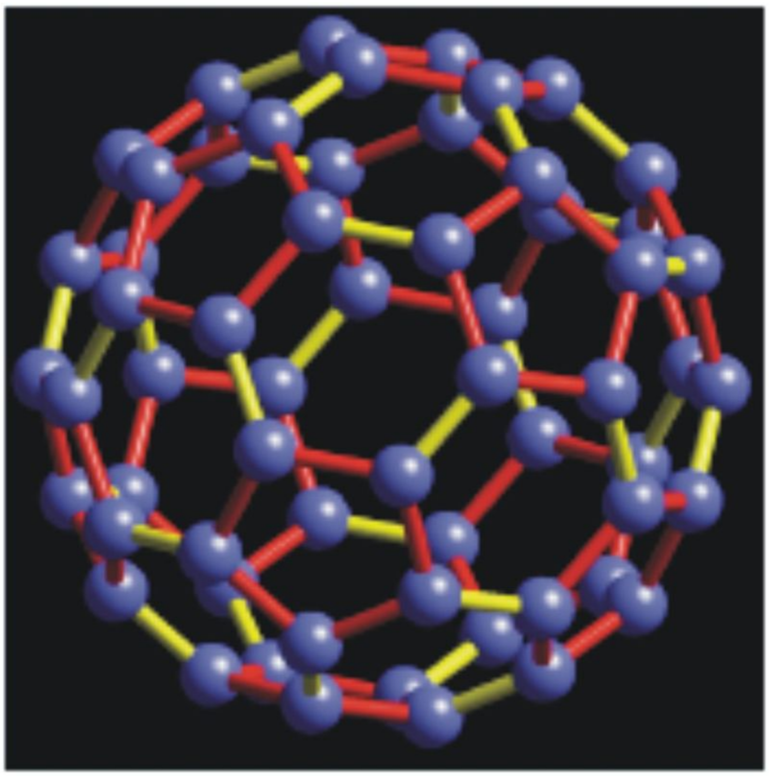
FIGURE 1.8

- 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

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)

Biological Nanomachines in Nature



Model of Buckminsterfullerene

FIGURE 1.9

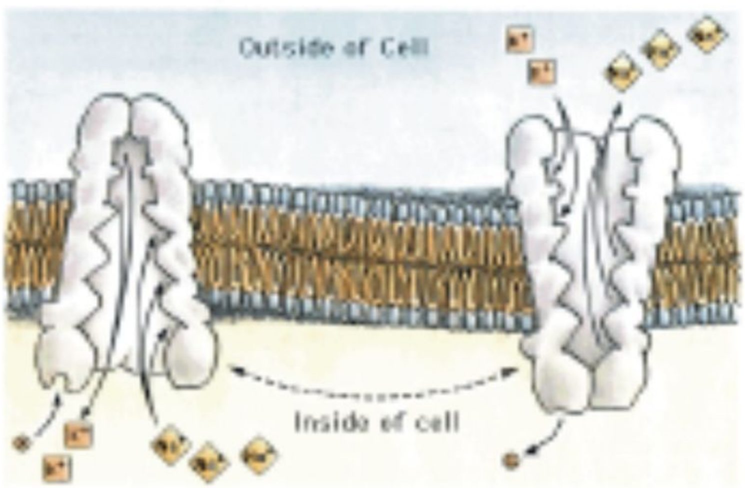
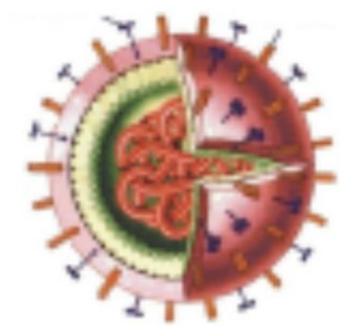


FIGURE 1.10



Influenza virus

- 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

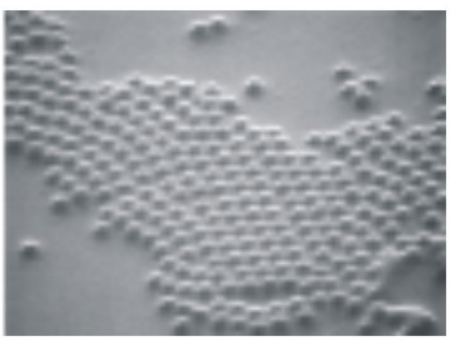
Building Nanostructures

How do you build things that are so small?

Fabrication Methods

IBM logo assembled from individual xenon atoms

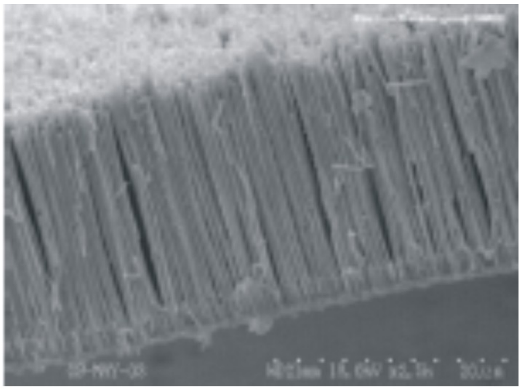
FIGURE 1.11



Polystyrene spheres selfassembling

- 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)

Example: Self Assembly By Crystal Growth



Growing a forest of nanotubes!

FIGURE 1.12

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

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) [U+0080] [U+009 where properties of matter differ significantly from those at larger scales. This very small scale is difficult for people to visualize. There are several sizeand 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/scien 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!

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.

Scale of Objects

Contents

- Scale of Objects: Teacher Lesson Plan
- Number Line/Card Sort Activity: Teacher Instructions #38; Key
- Cutting it Down Activity: Teacher Instructions #38; Key
- Scale of Objects Activity: Teacher Key
- Scale of Small Objects Quiz: Teacher Key

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 nano-sized 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

TABLE 1.10:

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 Cutting it Down Activity or Scale of Objects Activity	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) Photocopies of Cutting It Down Activity: Student Instructions & Worksheet Strips of Paper Scissors 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 #38; 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 #38; 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 , $\text{Log}_{10}(10^{-10}) = -10$. So, each card unit represents an exponent $(-10, -9, -8 \ldots -1, 0)$ 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., #38; Minogue, J. (2005). Conceptual Boundaries and Distances: Students' and Experts' Concepts of the Scale of Scientific Phenomena. *Journal of Research in Science Teaching.*

TABLE 1.11: Size (meters) and Objects table

Size (meters)	Objects
10°	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

TABLE 1.11: (continued)

Size (meters)	Objects
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 powers 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 #38; 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 8.5×11 inch sheet of paper, approximately 8.5 inches long by $1/4$ inch wide, or 216 mm $\times$ 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] Adaped 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.

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 ¯m) [Between 10^{-7} and 10^{-6} meters]

D. Between 1 micrometer (1 ¯m) 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]

F. Between 1 centimeter (1 cm) and 1 meter (m) [Between 10^{-2} and 10° meters]

G. Between 1 meter and 10 meters [Between 10° and 10^{1} meters]

H. More than 10 meters [More than 10^{1} meters]

TABLE 1.12:

	Less than 1 nm	1 nm to 100 nm	100 nm to 1 ¯m	1 ¯m 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*						

TABLE 1.12: (continued)

	Less than 1 nm	1 nm to 100 nm	100 nm to 1 ¯m	1 ¯m to 1 mm	1 mm to 1 cm	1 cm to 1 m	1 m to 10 m	More than 10 m
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*							

TABLE 1.12: (continued)

	Less than 1 nm	1 nm to 100 nm	100 nm to 1 ¯m	1 ¯m to 1 mm	1 mm to 1 cm	1 cm to 1 m	1 m to 10 m	More than 10 m
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., #38; 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 (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 ¯m) [Between 10^{-7} and 10^{-6} meters]

D. Between 1 micrometer (1 ¯m) 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]

TABLE 1.13:

	Less than 1 nm	1 nm to 100 nm	100 nm to 1 μm	1μm 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*			

TABLE 1.13: (continued)

	Less than 1 nm	1 nm to 100 nm	100 nm to 1 μm	1μm to 1 mm	1 mm to 1 cm
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

b. 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_____

Unique Properties at the Nanoscale

Teacher Lesson Plan

Contents

- Unique Properties at the Nanoscale: Teacher Lesson Plan
- Unique Properties at the Nanoscale: PowerPoint with Teacher Notes
- Unique Properties Lab Activities: Teacher Instructions
- Unique Properties at the Nanoscale: Teacher Reading
- Unique Properties at the Nanoscale Quiz: Teacher Key

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

TABLE 1.14:

Day	Activity	Time	Materials
Prior to this lesson	*Homework: Reading: Size-Dependent Properties*	45 min	Photocopies of Size-Dependent Properties: Student Reading

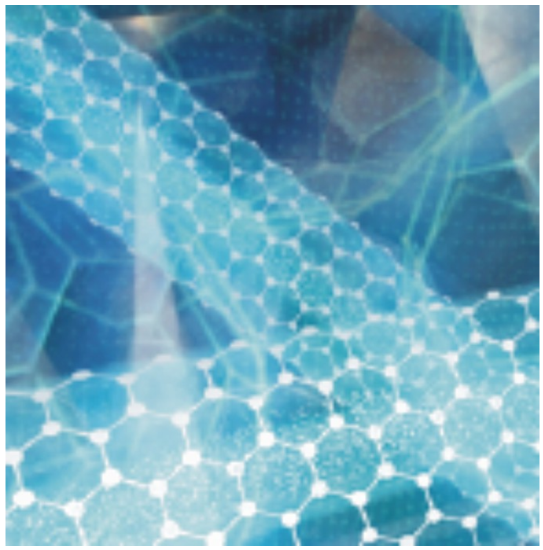
TABLE 1.14: (continued)

Day	Activity	Time	Materials
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	

TABLE 1.14: (continued)

Day	Activity	Time	Materials
	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

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)

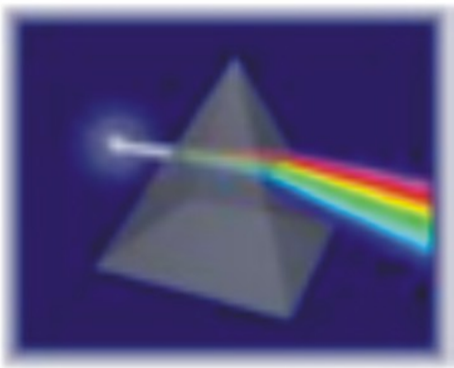
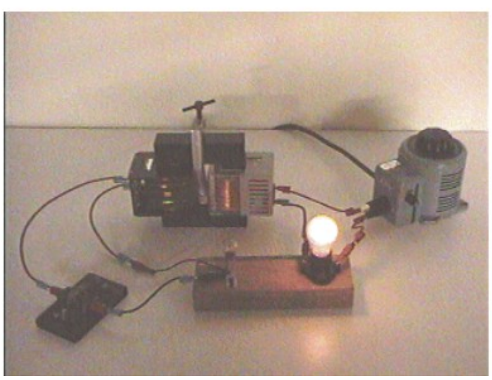


FIGURE 1.13



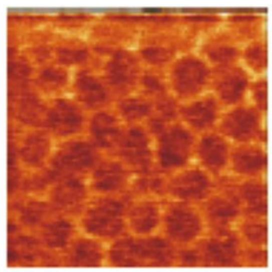
- Chemical (e.g. reactivity, reaction rates)

- Properties are usually measured by looking at large ($\sim 10^{23}$) aggregations of atoms or molecules

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 “Bulk” gold looks yellow particles look red

FIGURE 1.14

Optical Plroperties 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

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

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

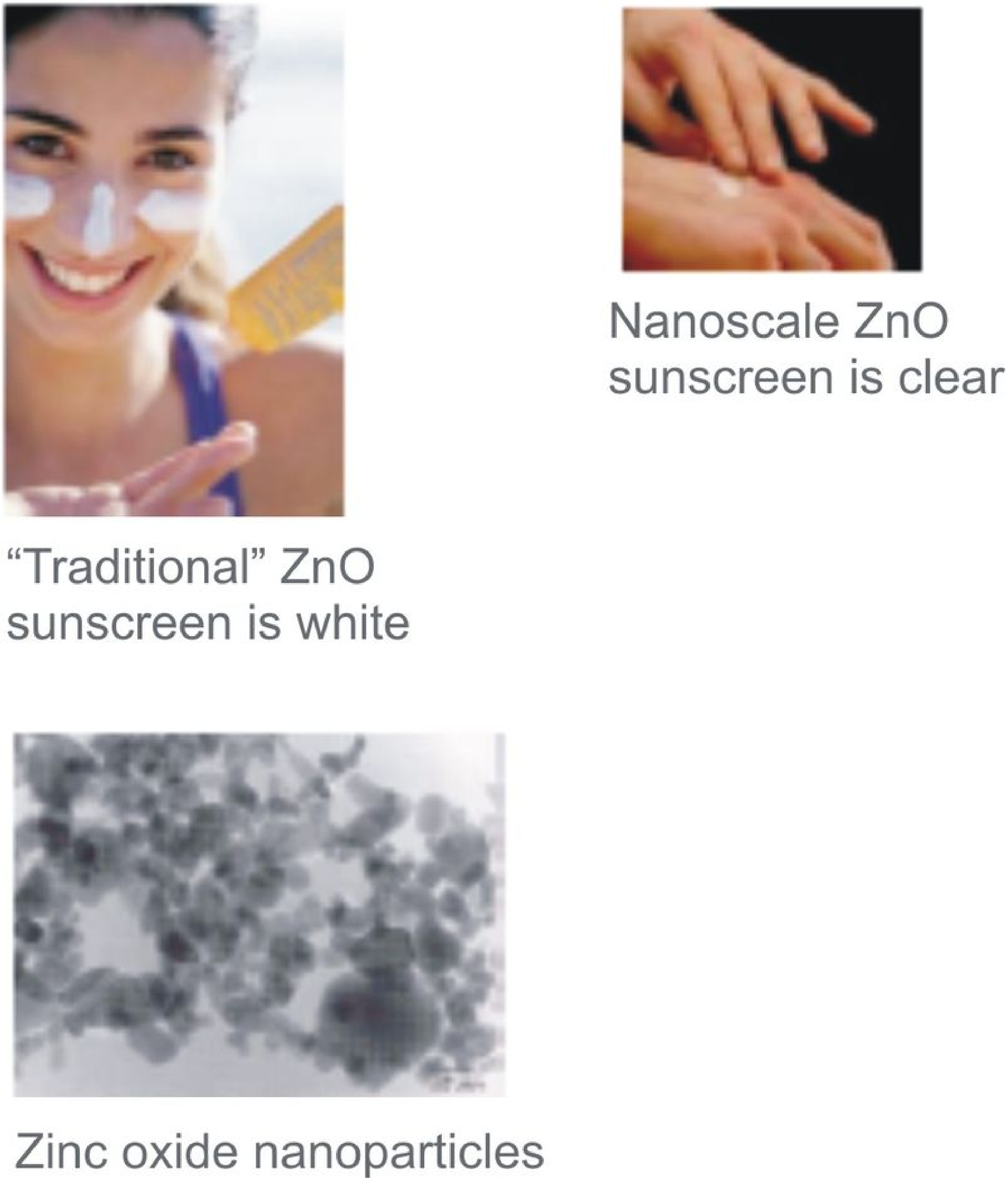

“Traditional” ZnO sunscreen is white
Nanoscale ZnO sunscreen is clear
Zinc oxide nanoparticles

FIGURE 1.15

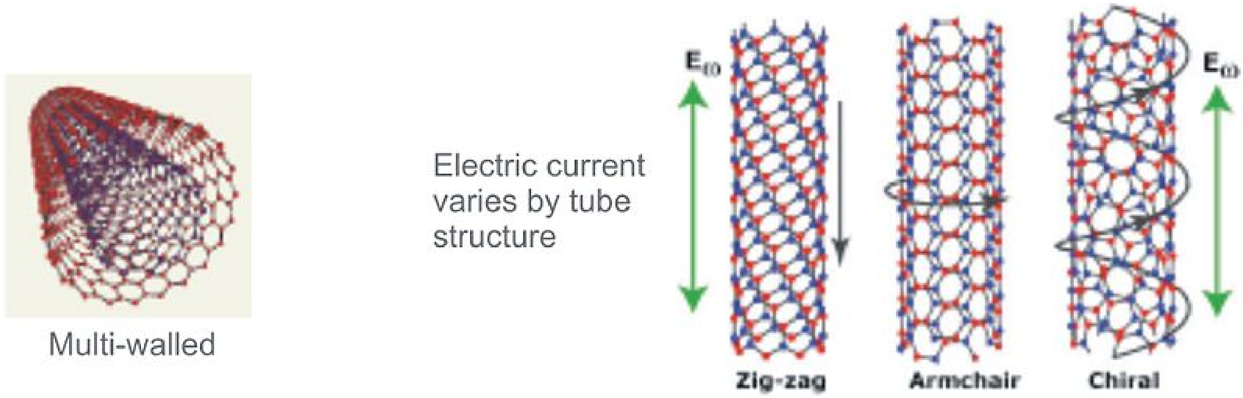


FIGURE 1.16

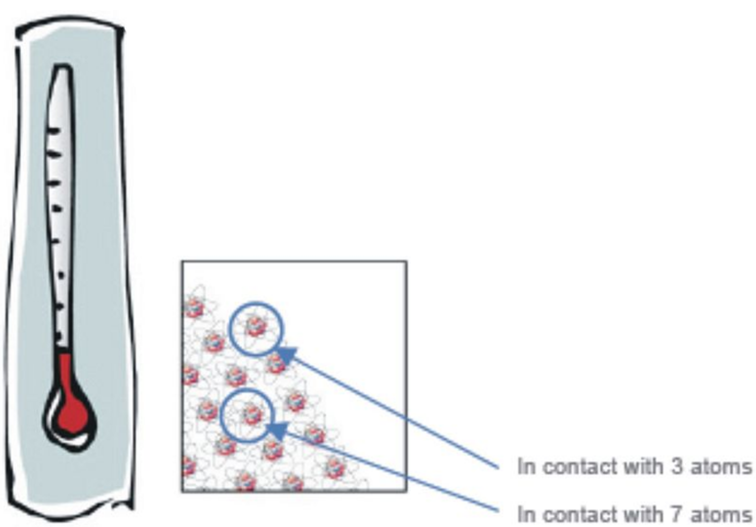
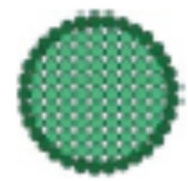


FIGURE 1.17

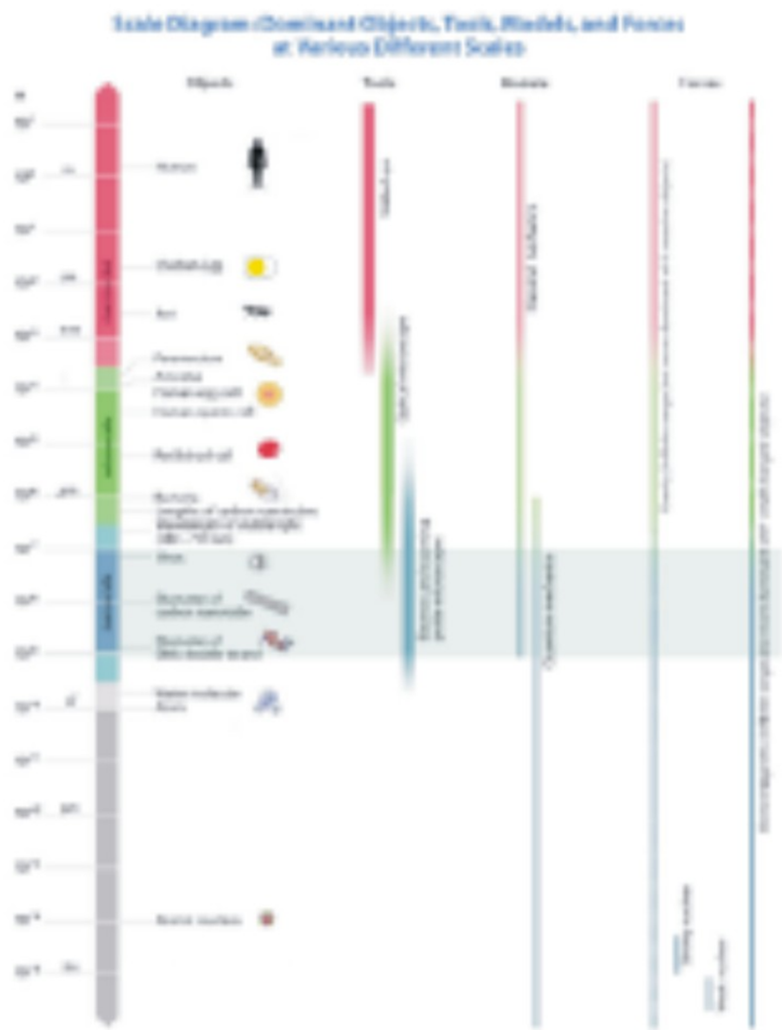
TABLE 1.15: Physical Properties Example: Melting Point of a Substance II

	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

Size-Dependant Properties

Why do properties change?

Scale Changes Everything



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

Scale Changes Everything II

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

Dominance of Electromagnetic Forces

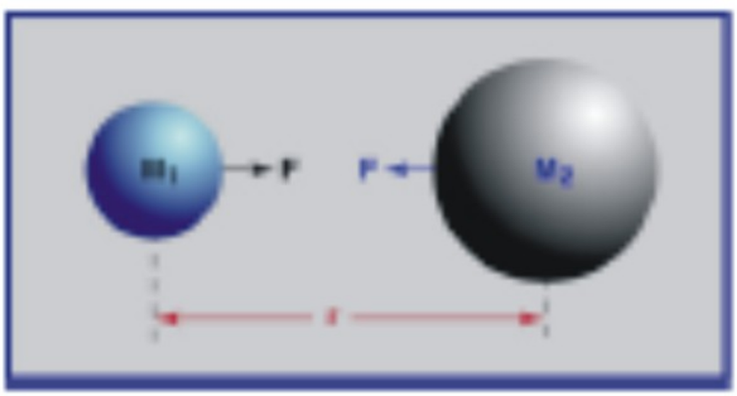
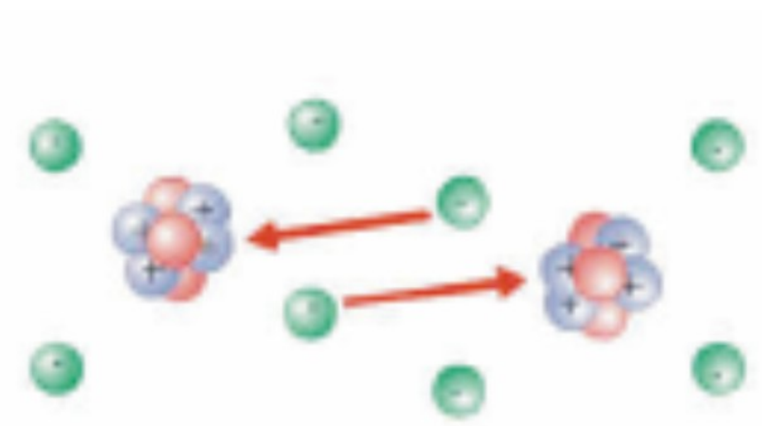


FIGURE 1.18



- 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!

Quantum Effects

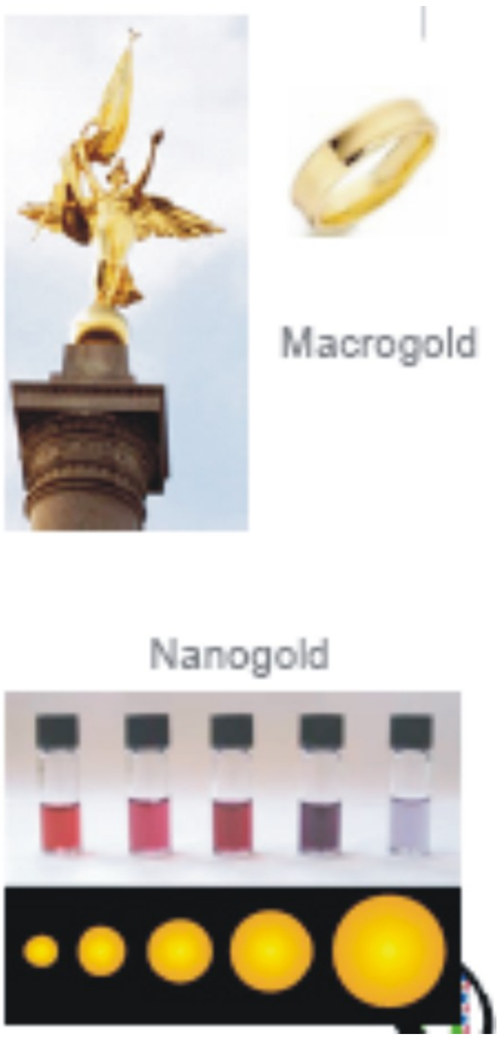


FIGURE 1.19

- 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

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

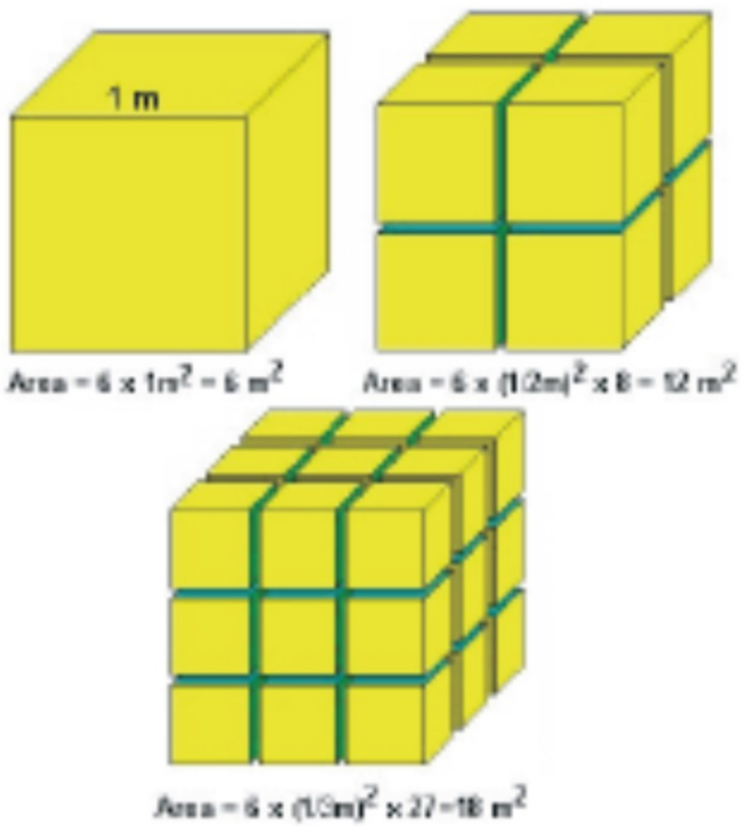


FIGURE 1.20

- This results in better catalysts, since a greater proportion of the material is exposed for potential reaction

Random Molecular Motion is Significant

FIGURE 1.21

- Tiny particles (like dust) move about randomly
  - At the macroscale, we barely see movement, or why it moves
  - At the nanoscale, the particle is moving wildly, batted about by smaller particles
- Analogy
  - Imagine a huge (10 meter) balloon being batted about by the crowd in a stadium. From an airplane, you barely see movement or people hitting it; close up you see the balloon moving wildly.

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

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 sizedependent 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/brow

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.

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 100 nm), 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

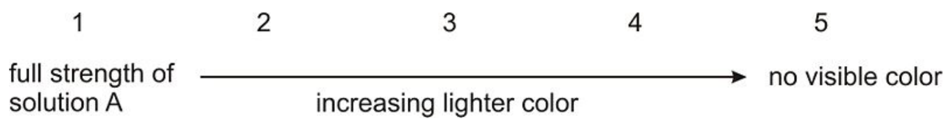
1. Label each of your test tubes from 1 to 5 .
2. Use a pipette to place 10.0 mL of 1.0 Molar of colored solution into test tube #1.
3. Remove 1.0 mL from test tube #1 and inject this into test tube #2. Then add 9.0 mL of water into test tube #2.
4. Remove 1.0 mL from test tube #2 and inject this into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



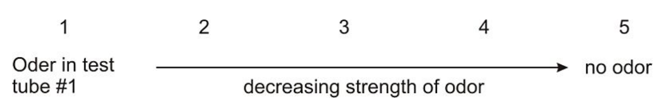
4. **Record on your lab sheet** the strength of each test tube according to the scale above. At what strength are you no longer able to detect color? Explain why this has happened.

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.



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

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

Lab Station C: Bubbles Self-Assembly Lab

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

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

Lab Station D: Which Shape Can Dissolve the Fastest?

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

Lab Station E: Faster Explosion?

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

Lab Station F: Is All Water the Same?

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

Lab Station G: Burn Baby Burn!

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

Lab Station H: Bet I Can Beat'Cha!

- Copper(II)chloride dihydrate crystals $(CuCl_2 \bullet 2H_2O)$. Order from any chemical supply house.
- A plastic teaspoon that can be used for measuring the crystals
- One glass-stirring rod. [If a stirring rod is unavailable, the teaspoon may be used to stir. **Caution:** Once the teaspoon has been used to stir the solution, it cannot be used again for measuring out the crystals.
- Two 100 – mL beakers
- Two squares, 2 inches $\times$ 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

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 1.16: 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.

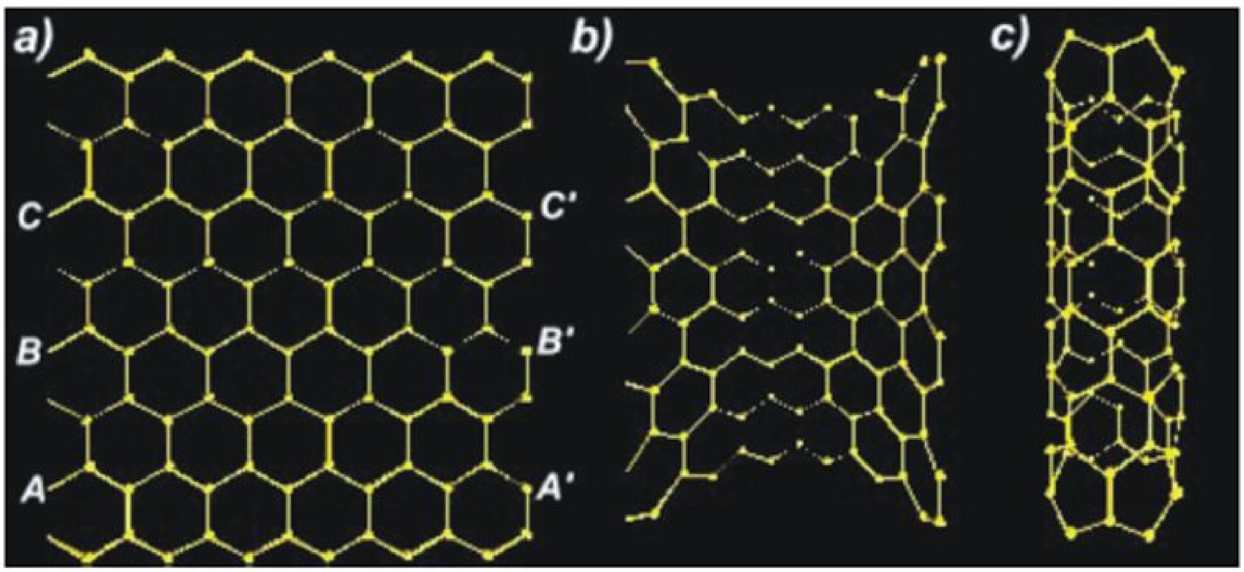


FIGURE 1.22

A plane of graphite *left* rolled up *middle* gives you a nanotube *right* matching points A with A´ B with B´ and so forth

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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; $-143^\circ C$). 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 $(127^\circ C)$, 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.

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).

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.

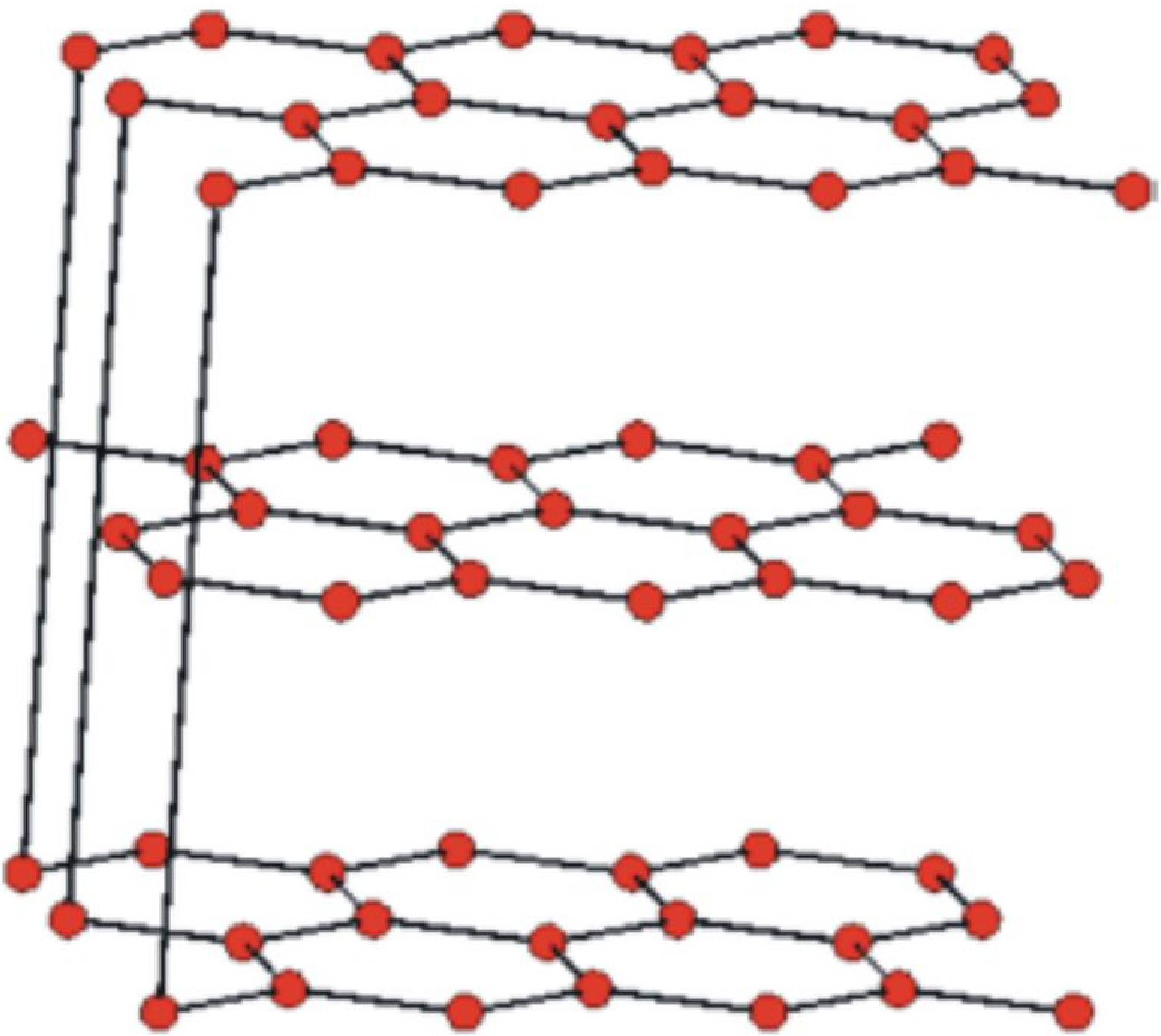

FIGURE 1.23

Layered lattice structure of graphite with widely separated planes that are only weakly held together by weak van der Waals forces

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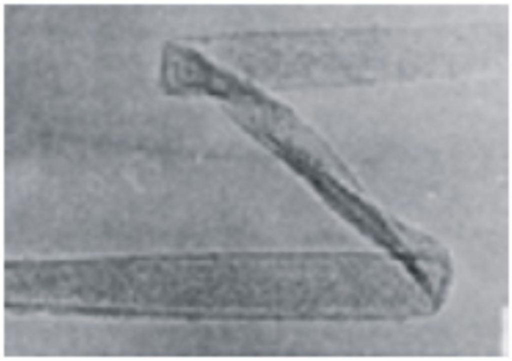

FIGURE 1.24
A severely distorted nanotube still doesn&#8217 t break

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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!

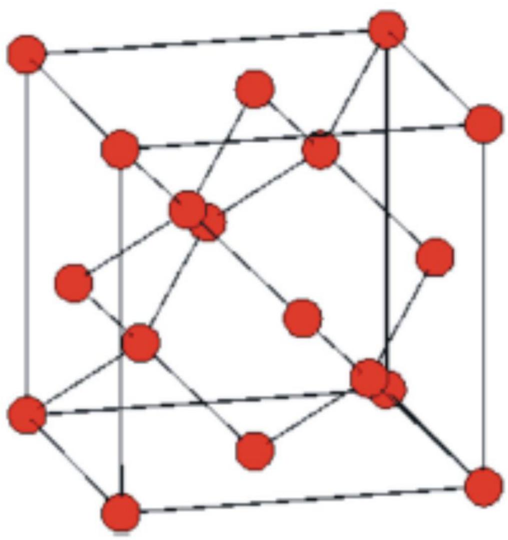

FIGURE 1.25
In diamond each carbon atom forms bonds tetrahedrally arranged to other carbon atoms resulting in a very strongly bonded 3D structure. Very small diameter carbon nanotubes could be as strong as diamond.

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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 1.17: 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.

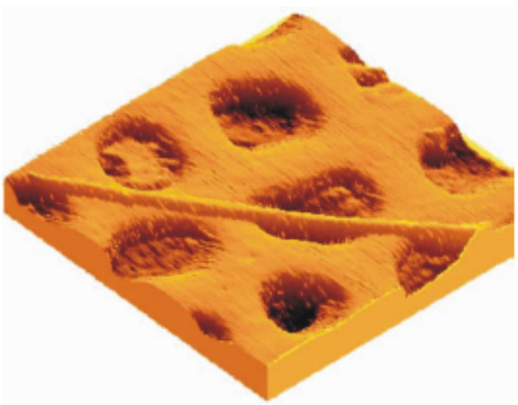

FIGURE 1.26
A carbon nanotube on a porous ceramic membrane ready for mechanical measurements by AFM

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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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Optical properties

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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.

Tools of the Nanosciences

Teacher Lesson Plan

Contents

- Tools of the Nanosciences: Teacher Lesson Plan
- Scanning Probe Microscopy: Teacher Reading
- Scanning Probe Microscopy: PowerPoint with Teacher Notes
- Black Box Activity: Teacher Instructions #38; Key
- Seeing and Building Small Things Quiz: Teacher Key
- Optional Extensions for Exploring Nanoscale Modeling Tools: Teacher Notes

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

TABLE 1.18:

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	

TABLE 1.18: (continued)

Day	Activity	Time	Materials
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 Angstrom (.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.

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.

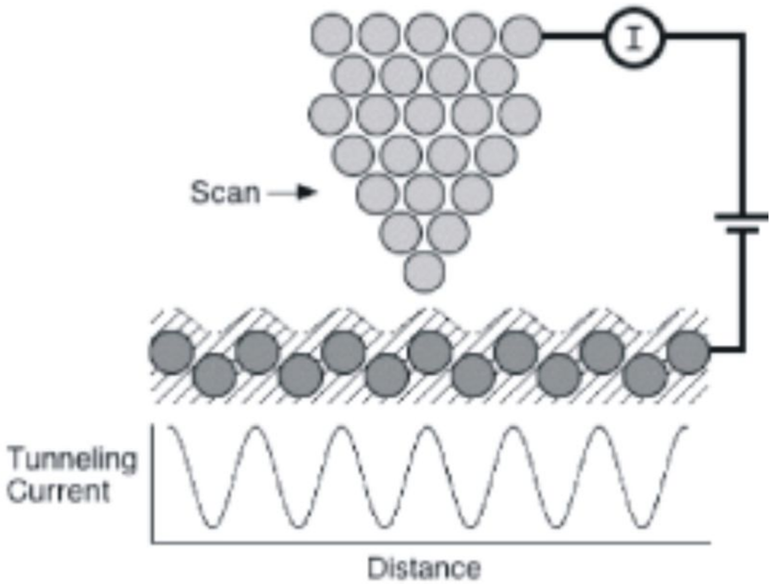

FIGURE 1.27
Tip and surface and electron tunneling

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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.

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.

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

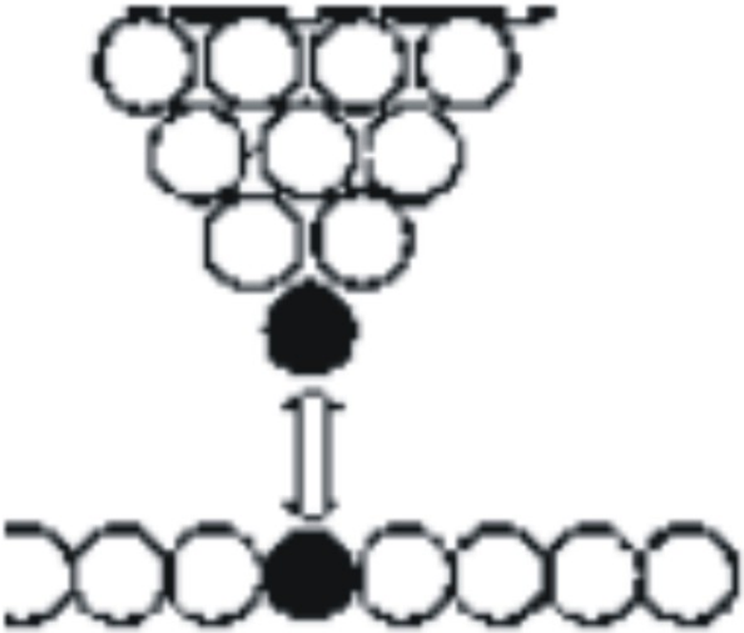


FIGURE 1.28
An STM tip

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).

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.

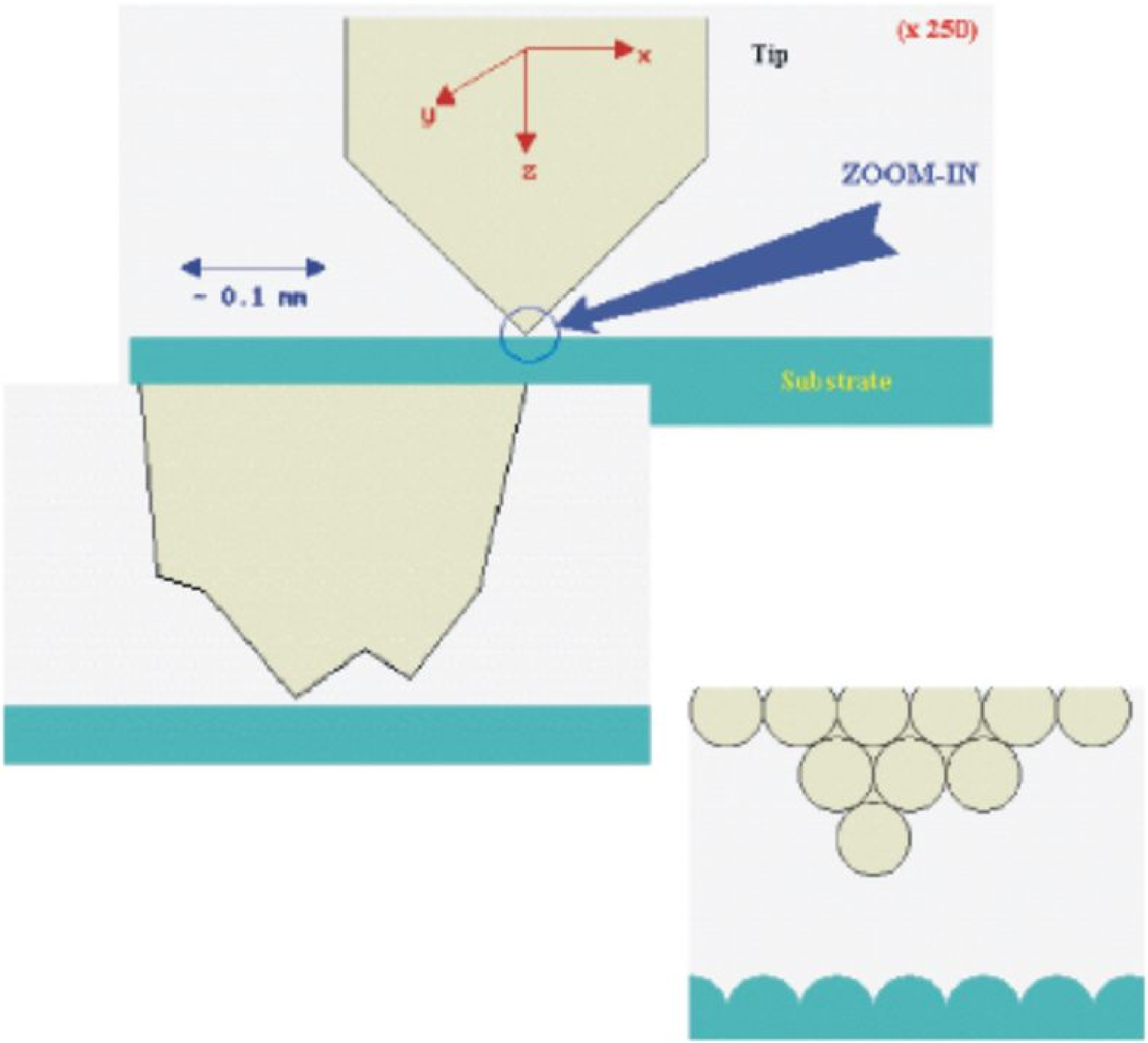


FIGURE 1.29

Zoom in of tip

3

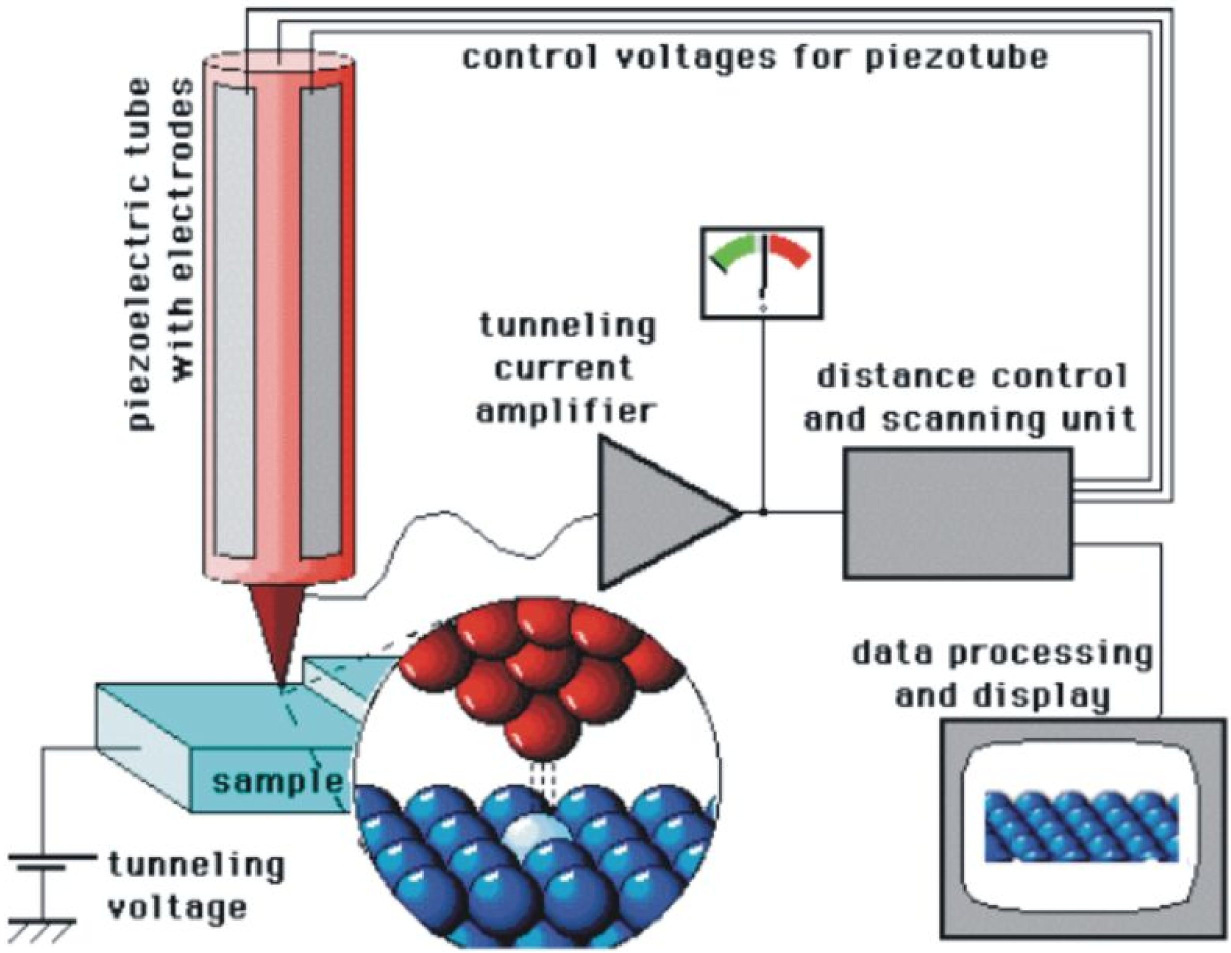


FIGURE 1.30
Diagram of an STM

4

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.

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.

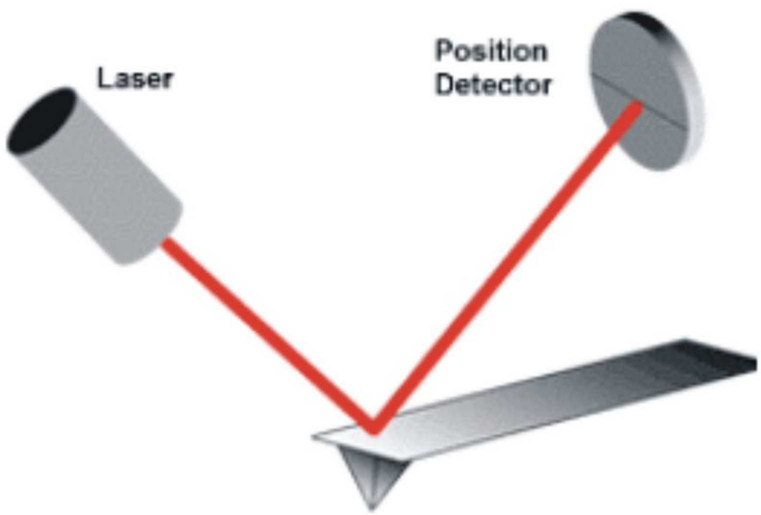


FIGURE 1.31

Laser used to measure cantilever movement

5

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 vander 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.

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.)

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

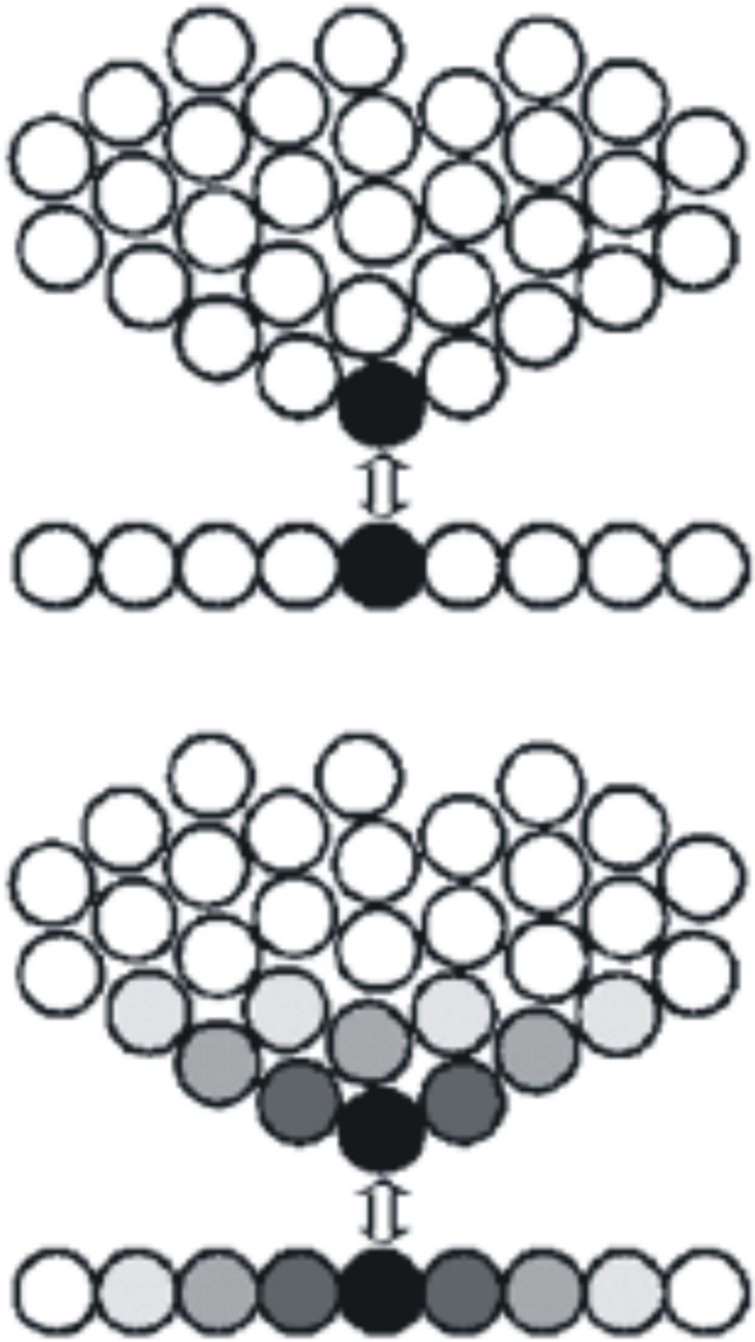


FIGURE 1.32

Interatomic interaction for STM top and AFM $bottom$ shading shows interaction strength

6

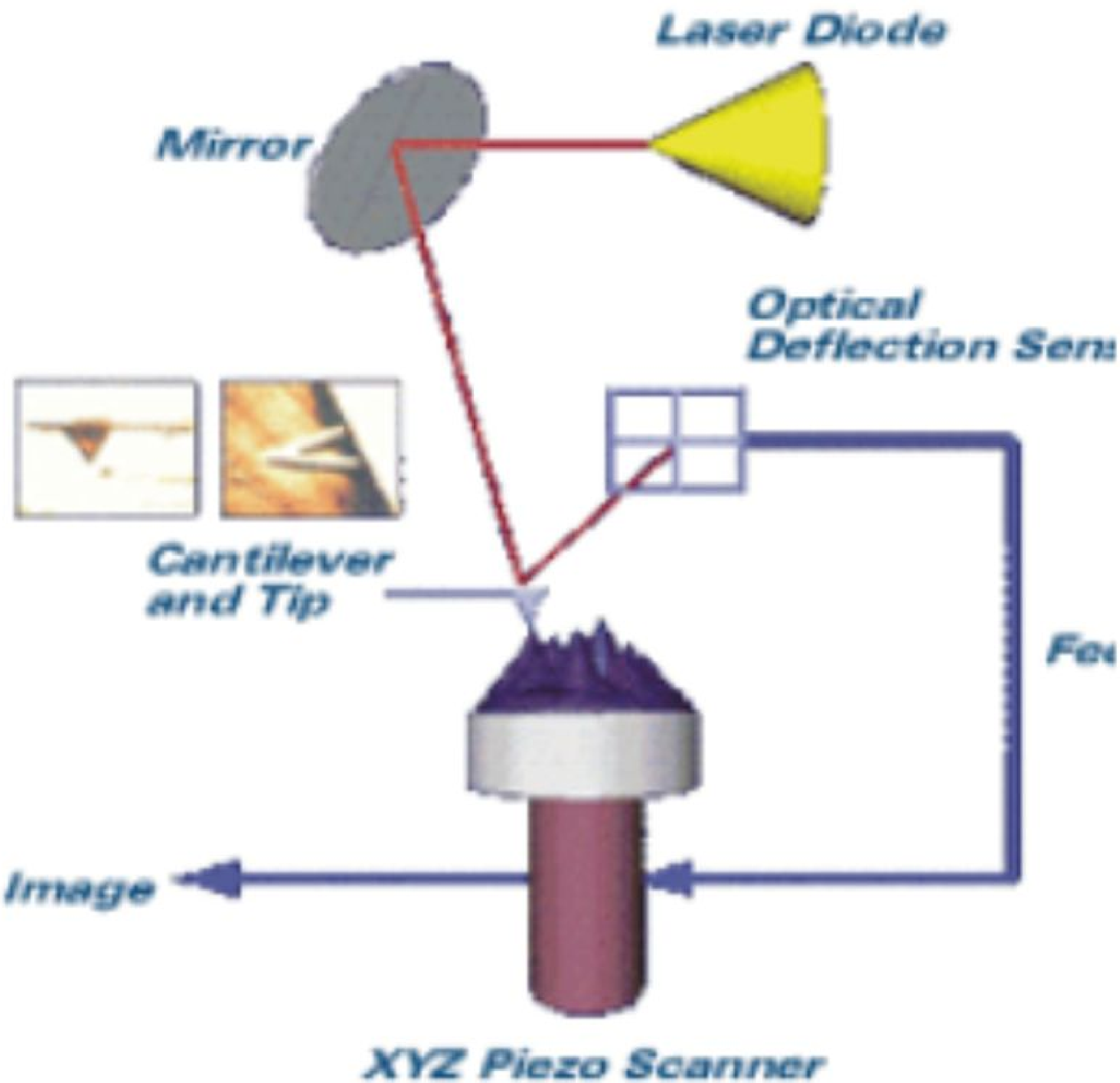


FIGURE 1.33
How the AFM works

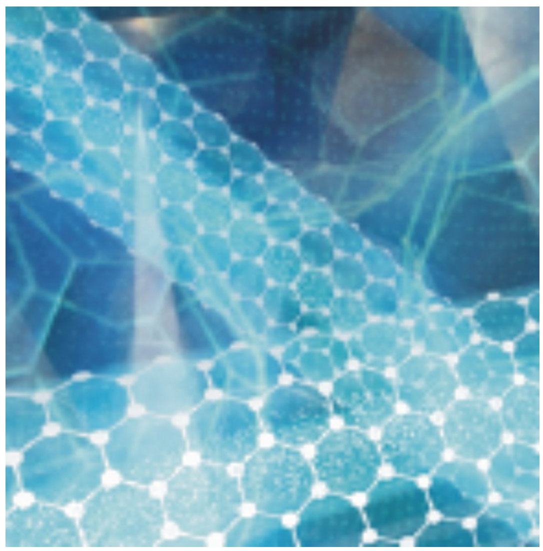
7

- http://mechmat.caltech.edu/ kaushik/park/3-3-0.htm
- http://www.chem.qmw.ac.uk/surfaces/scc/scat7_6.htm
- http://www.iap.tuwien.ac.at/www/surface/STM_Gallery/stm_animated.gif
- http://www.nanoscience.com/education/AFM.html
- http://mechmat.caltech.edu/ kaushik/park/3-3-0.htm
- 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

Scanning Probe Microscopes (SPMs)

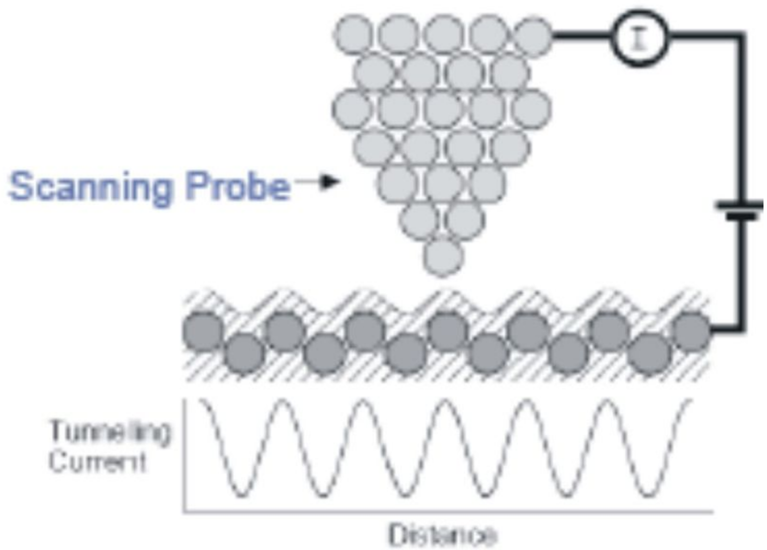
- Monitor the interactions between a probe and a sample surface
- What we "see" is really an image
- Two types of microscopy we will look at:
  - Scanning Tunneling Microscope (STM)
  - Atomic Force Microscope (AFM)

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

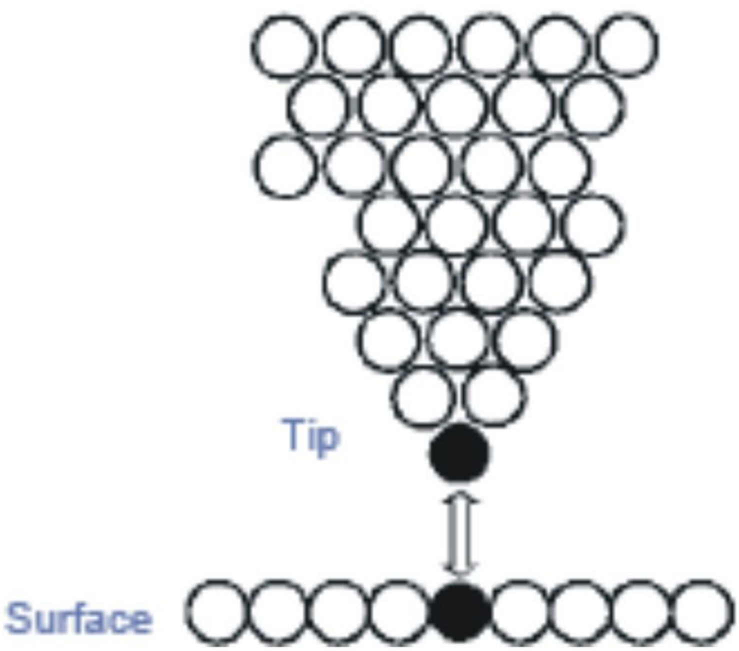
STM Tips

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



Tip and surface and electron tunneling

FIGURE 1.34



Tunneling current depends on distance between tip and surface

FIGURE 1.35

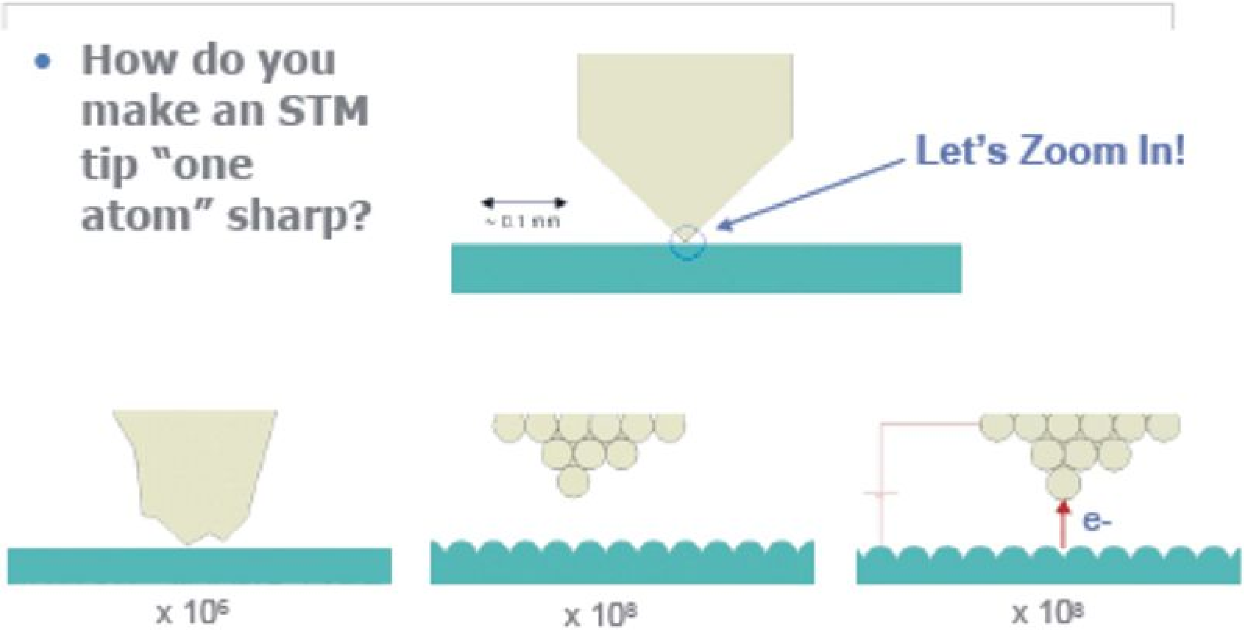


FIGURE 1.36

STM Tips II

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

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

Challenges of the STM

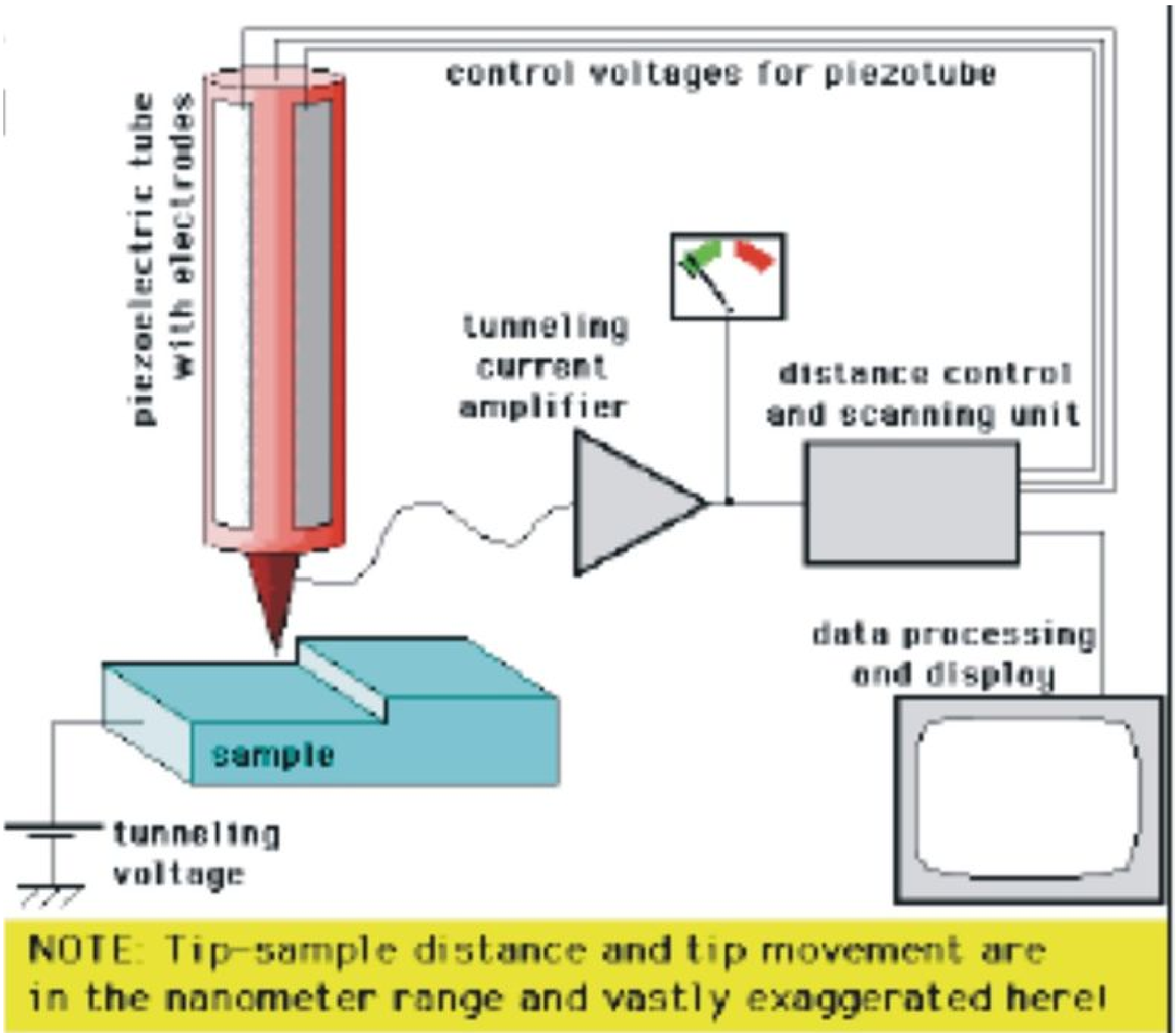
- Works primarily with conducting materials
- Vibrational interference
- Contamination
  - Physical (dust and other pollutants in the air)
  - Chemical (chemical reactivity)

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

AFM Tips

- The size of an AFM tip must be carefully chosen



control voltages for piezotube
piezoelectric tube with electrodes
tunneling current amplifier
distance control and scanning unit
data processing and display
sample
tunneling voltage
NOTE: Tip-sample distance and tip movement are in the nanometer range and vastly exaggerated here!

FIGURE 1.37

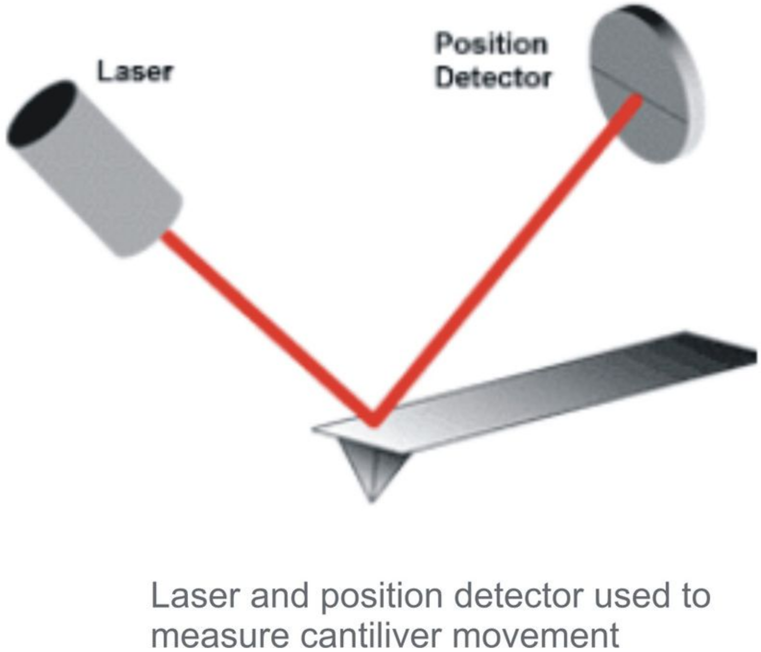


FIGURE 1.38

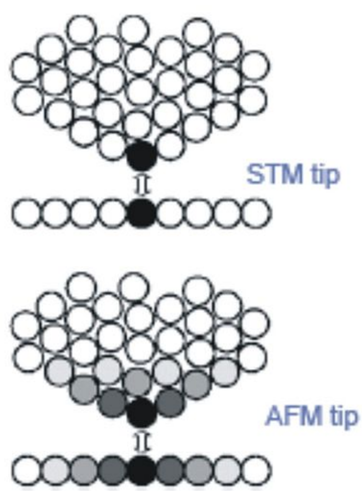


FIGURE 1.39

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

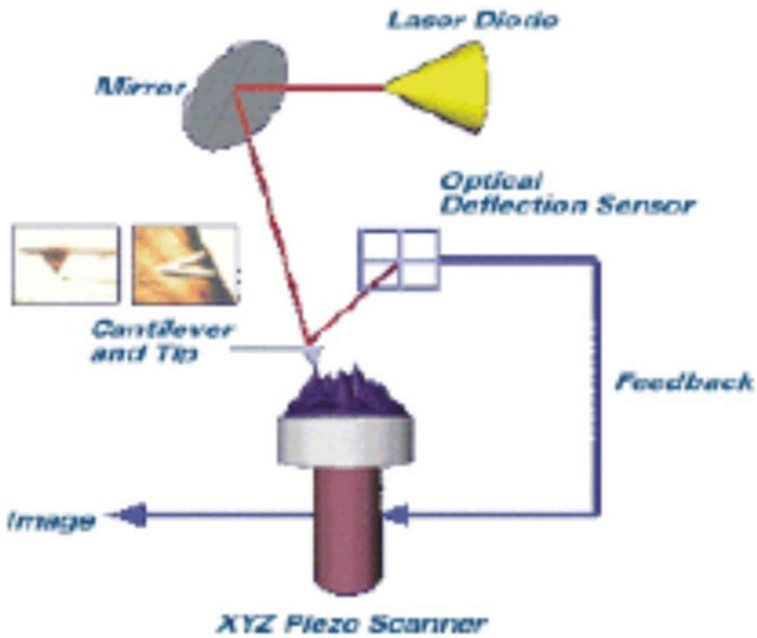


FIGURE 1.40

The AFM

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

So What Do We See?

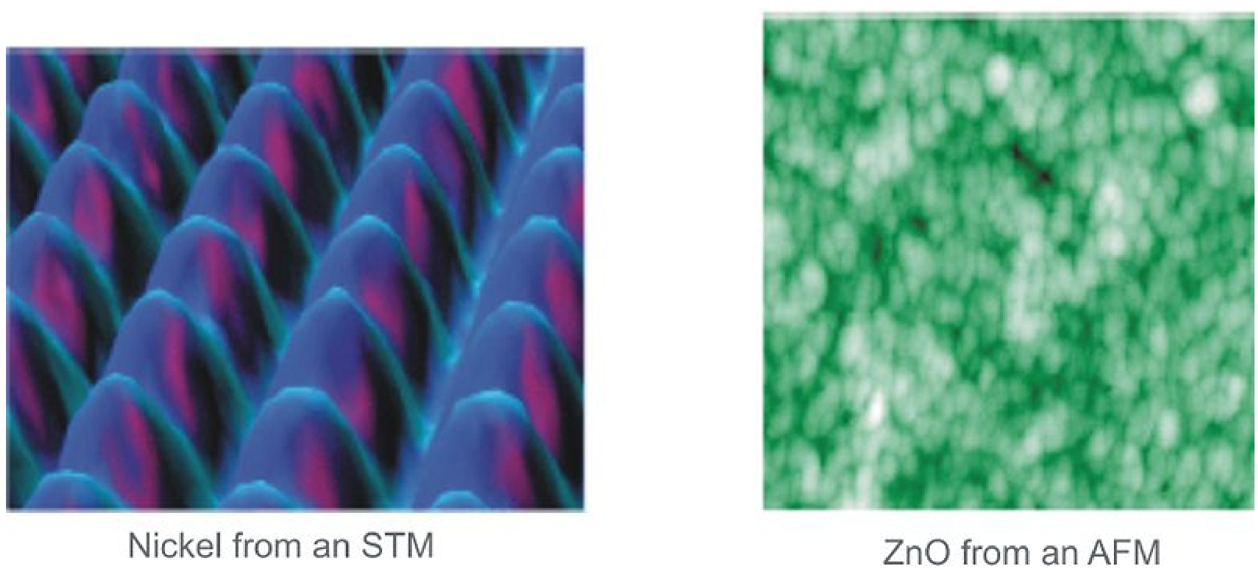
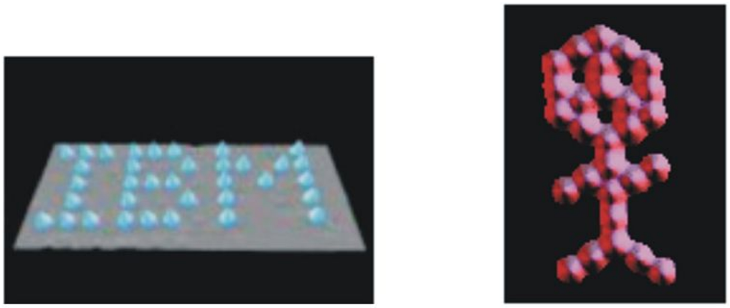


FIGURE 1.41

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

FIGURE 1.42

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 #38; 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.

Exploring Self Assembly

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

The Molecular Workbench (MW) software, available at for both Macintosh and Windows platforms, http://molo.concord.org/softw
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.

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

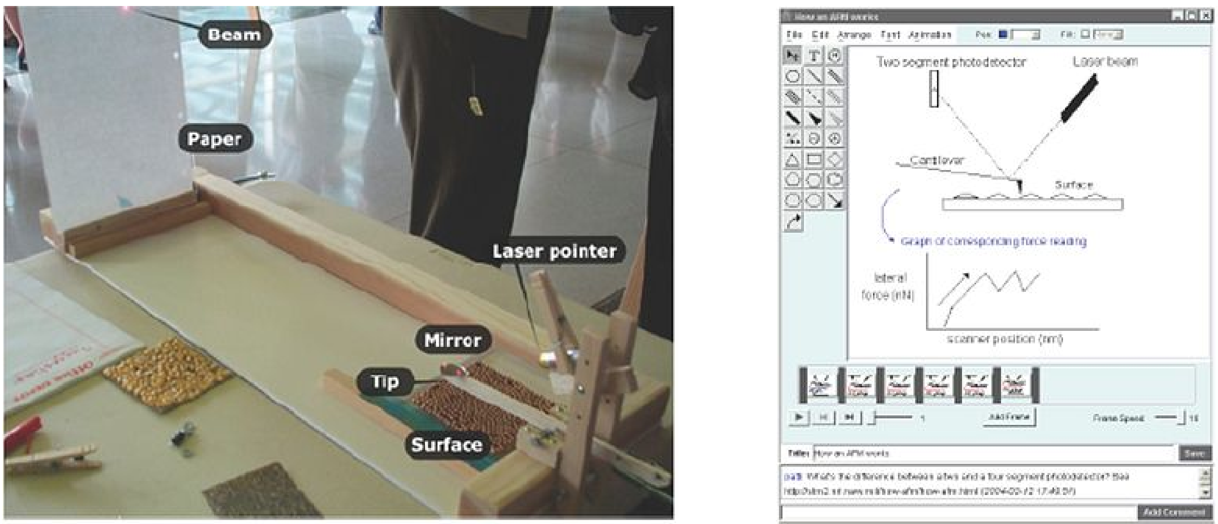


Figure 1. Wood AFM model.

Figure 2. Screen shot of a ChemSense assessment activity.

FIGURE 1.43

Wood AFM model

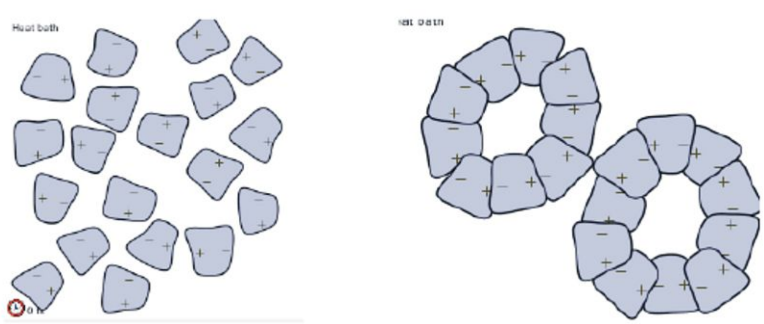


FIGURE 1.44

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.

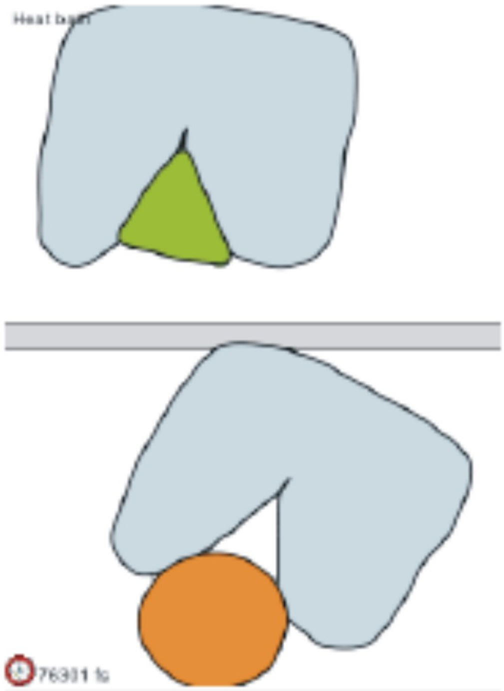


FIGURE 1.45
The importance of shape in docking

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.

Applications of Nanoscience

Teacher Lesson Plan

Contents

- Applications of Nanoscience: Teacher Lesson Plan
- Applications of Nanoscience: PowerPoint with Teacher Notes
- What's New Nanocat? Poster Session: Teacher Instructions #38; Rubric

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

TABLE 1.19:

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

TABLE 1.19: (continued)

Day	Activity	Time	Materials
	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.

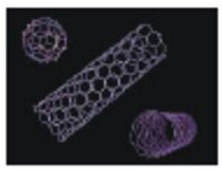
Applications of Nanoscience

How might nanoscale science and engineering improve our lives?

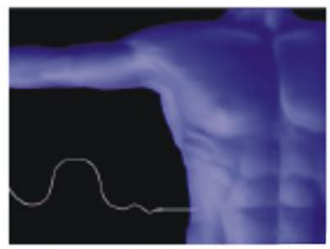
Potential Impacts of Nanotechnology

- 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

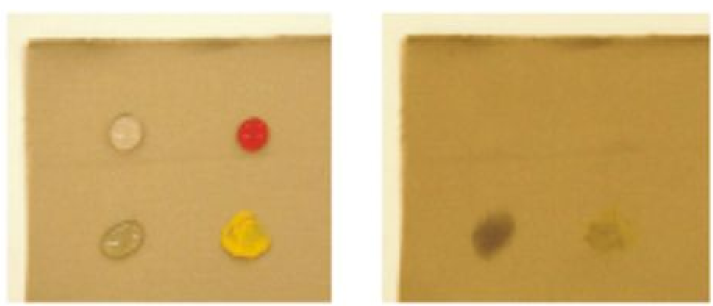


Possible entry point for nanomedical device

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)

FIGURE 1.46

Materials: Paint That Doesn't Chip

Mercedes covered with tougher, shinier nanopaint

FIGURE 1.47

- 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?

Environment: Paint That Cleans Air

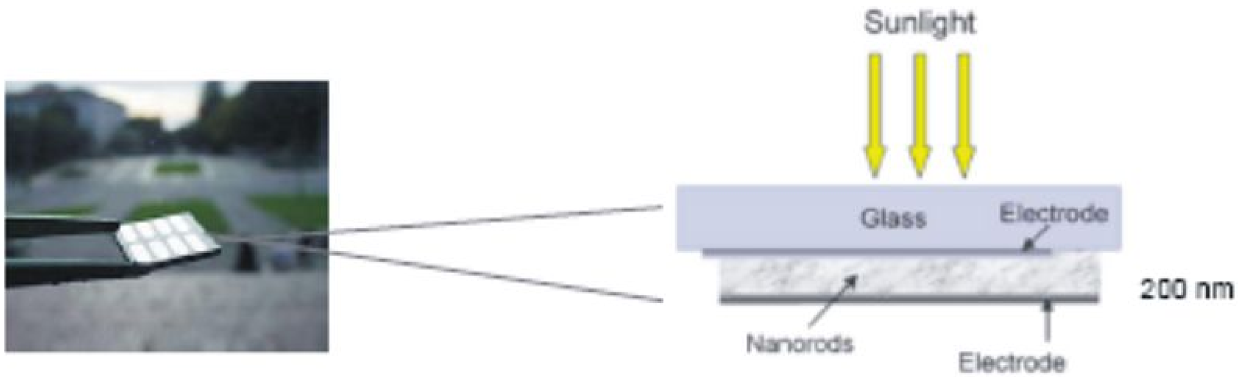
Buildings as air purifiers?

FIGURE 1.48

- Nanopaint on buildings could reduce pollution
  - When exposed to ultraviolet light, titanium dioxide (TiO_2) nanoparticles in paint break down organic and inorganic pollutants that wash off in the rain
  - Decompose air pollution particles like formaldehyde

Environment: Nano Solar Cells

- Nano solar cells mixed in plastic could be painted on buses, roofs, clothing



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

FIGURE 1.49

- Solar becomes a cheap energy alternative!

Technology: A DVD That Could Hold a Million Movies

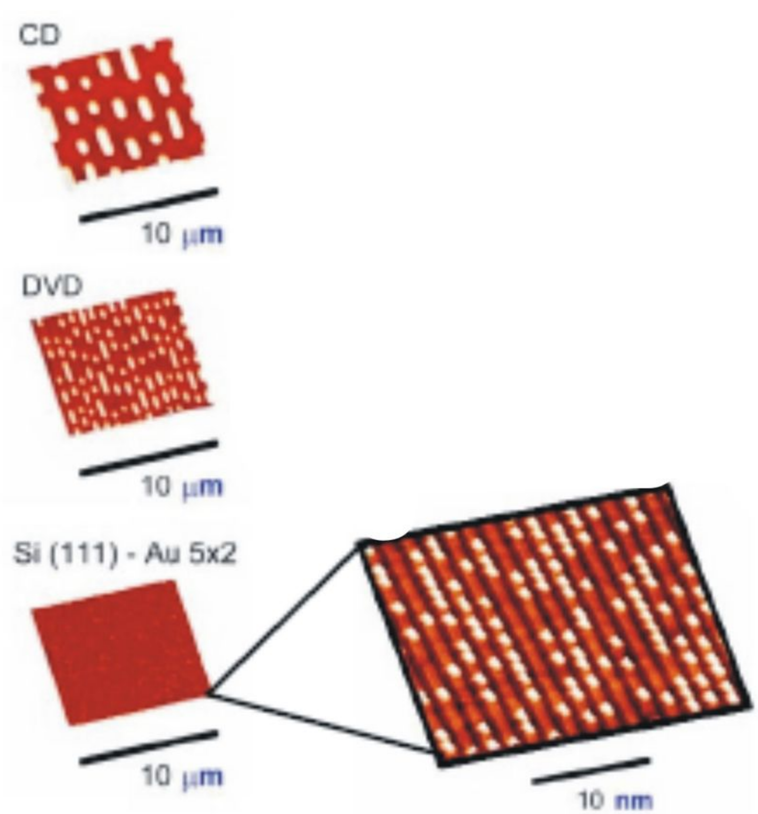


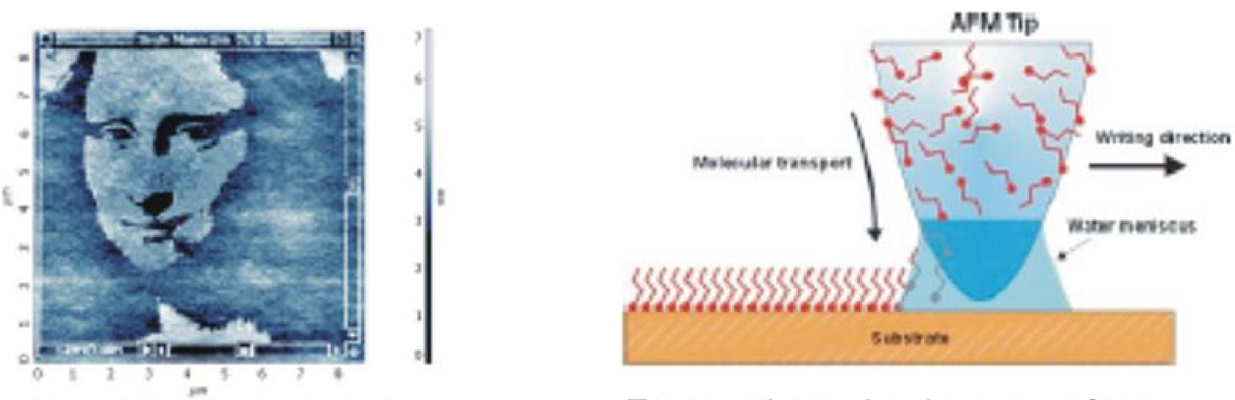
FIGURE 1.50

- 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!

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

FIGURE 1.51

Health Care: Nerve Tissue Talking to Computers

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

Health Care: Detecting Diseases Earlier

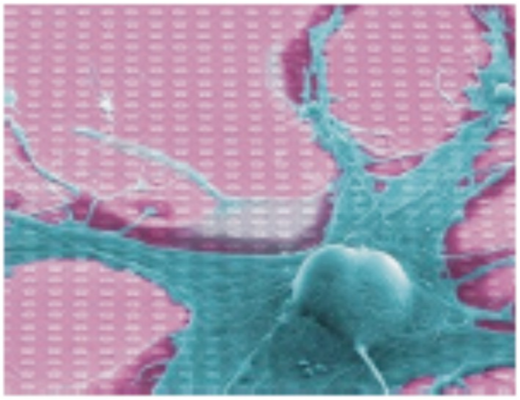
- Quantum dots glow in UV light
  - Injected in mice, collect in tumors
  - Could locate as few as 10 to 100 cancer cells

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

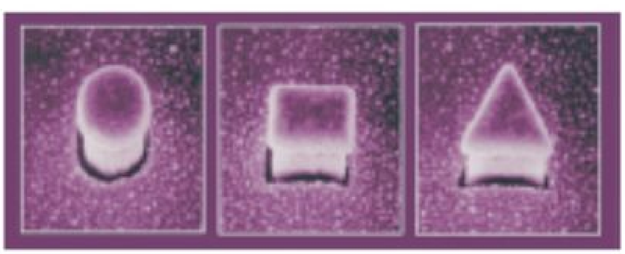
Health Care: Preventing Viruses from Infecting Us

- Nanocoatings over proteins on viruses
  - Could stop viruses from binding to cells

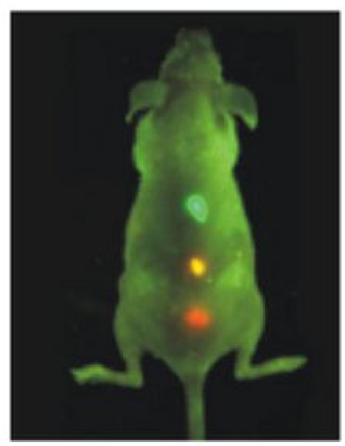


Snail neuron grown on a chip
that records the neuron's activity

FIGURE 1.52

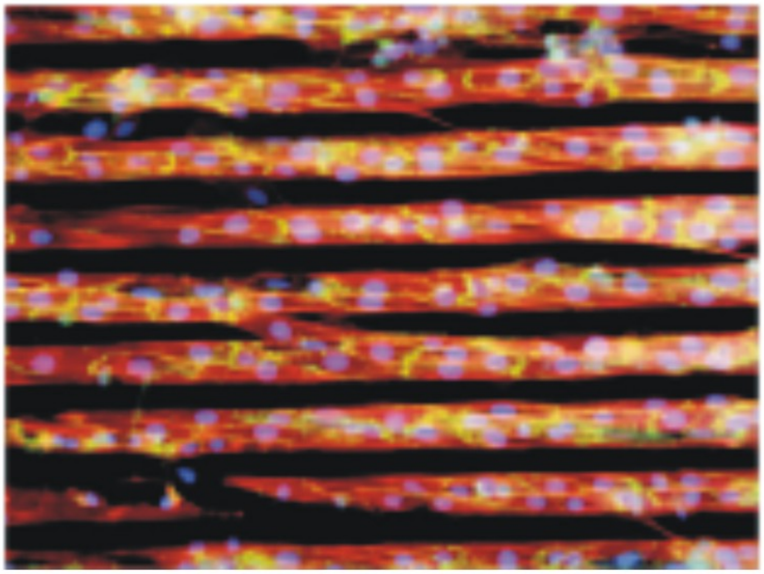


Quantum Dots: Nanometer-sized crystals that contain free electrons and emit photons when submitted to UV light



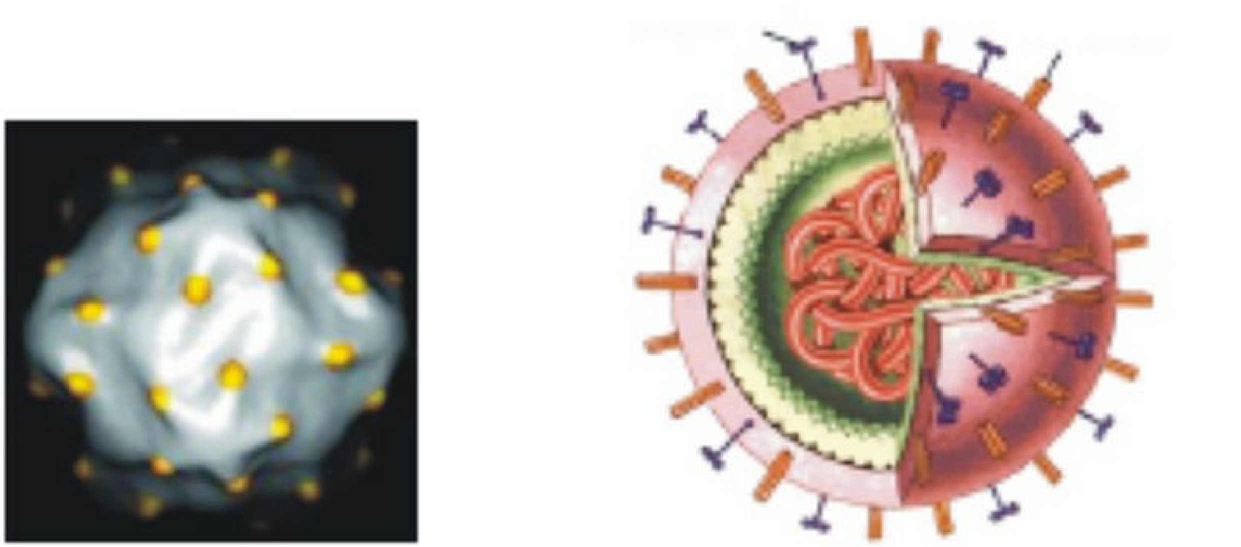
Early tumor detection, studied in mice

FIGURE 1.53



Cardiac tissue grown with the help of nanofiber filaments

FIGURE 1.54



Gold tethered to the protein shell of a virus

Influenza virus: Note proteins on outside that bind to cells

FIGURE 1.55

- Never get another cold or flu?

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

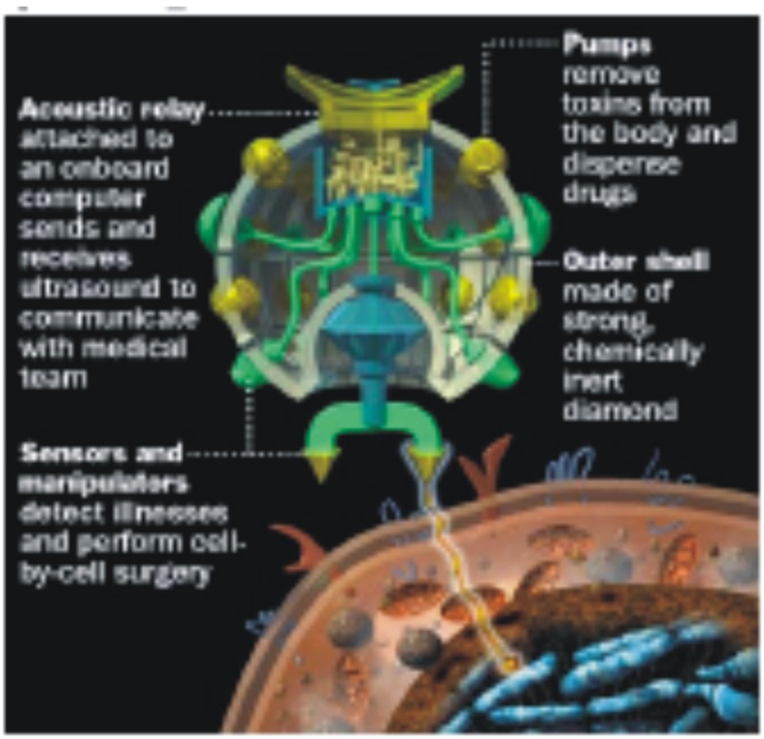


FIGURE 1.56

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

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

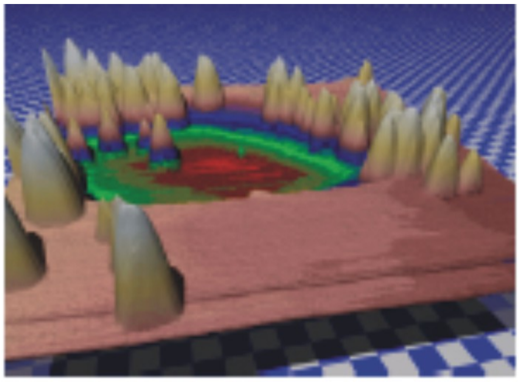


FIGURE 1.57

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

- 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

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: htm http://www.nanotech-now.com/currentuses. 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#38;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/

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 Principles/Lithographies/AFM_Oxidation_Lithography_mode37.html http://www.ntmdt 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 128×128 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 neuroelectronic 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/8148/8148coun

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 highenergy 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: fects_Brief_090804.html http://www.trnmag.com/Stories/2004/090804/Nano_men fects_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, realworld examples of science in action.

What's New Nanocat? Poster Session: Teacher Instructions #38; 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.

TABLE 1.20: Rubric for NanoCat Poster Evaluation

	Novice (1) Absent, inaccurate, or confused	Apprentice (2) Partially developed	Skilled (3) Adequately developed	Masterful (4) Fully developed
Written explanations	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 explanations	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.
Attractiveness	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.
Attribution	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.

TABLE 1.20: (continued)

	Novice (1) Absent, inaccurate, or confused	Apprentice (2) Partially developed	Skilled (3) Adequately developed	Masterful (4) Fully developed
Oral Team Presentation	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.

One-Day Introduction to Nanoscience

Teacher Lesson Plan

Contents

- One-Day Introduction to Nanoscience: Teacher Lesson Plan
- One-Day Introduction to Nanoscience: Teacher Demonstration Instructions
- One-Day Introduction to Nanoscience: PowerPoint with Teacher Notes

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

TABLE 1.21:

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	

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.

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 $70-90\text{ nm}$.

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.

FIGURE 1.58

Mesogold colloidal gold from Purest Colloids Inc.

1

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.

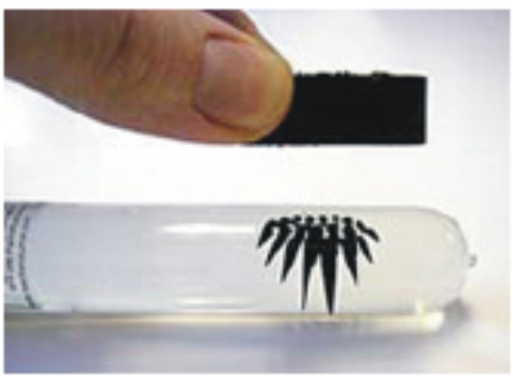


FIGURE 1.59

Ferrofluid from Educational Innovations Inc.

2

When the magnet is removed, the spikes disappear. 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.

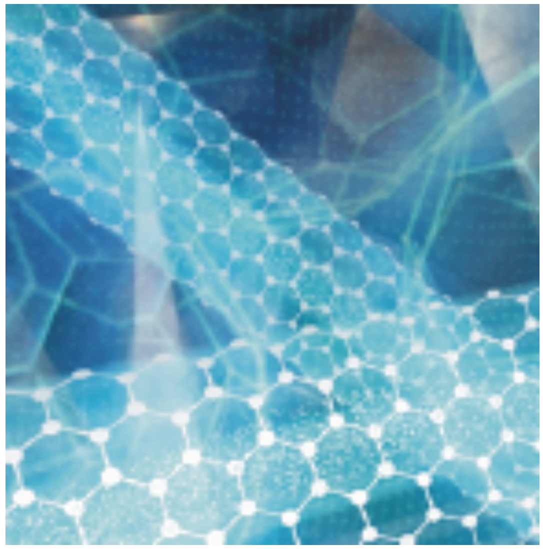
Where to Buy It

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

- http://www.purestcolloids.com/mesogold.htm
- https://www.teachersource.com
- http://jchemed.chem.wisc.edu/JCESoft/CCA/CCA2/MAIN/FEFLUID/CD2R1.HTM
- http://mrsec.wisc.edu/Edetc/background/ferrofluid/index.html
- 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!

What is Nanoscale Science?

FIGURE 1.60

- 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

How Big is a Nanometer?

- Consider a human hand

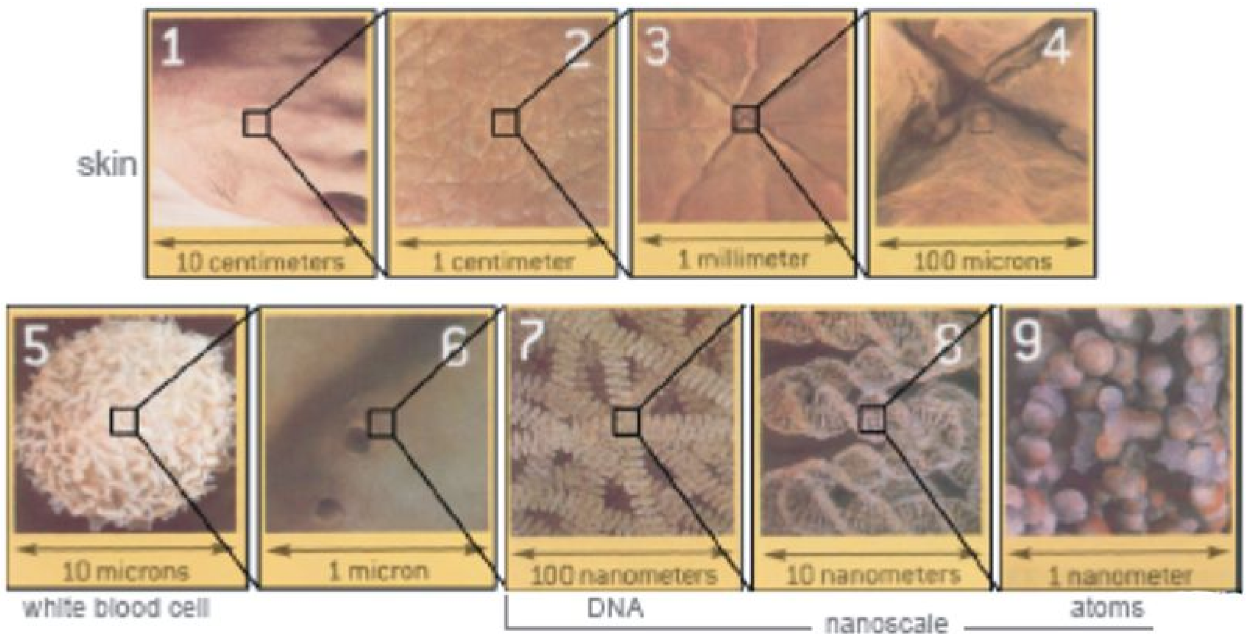


FIGURE 1.61

Are You a Nanobit Curious?

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

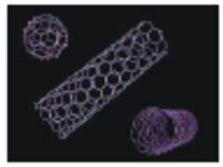
Potential Impacts

How might nanoscale science and engineering improve our lives?

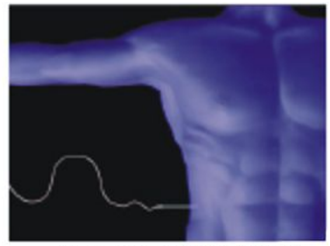
Innovations In Development or Under Investigation

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

Thin layers of gold are used in tiny medical devices



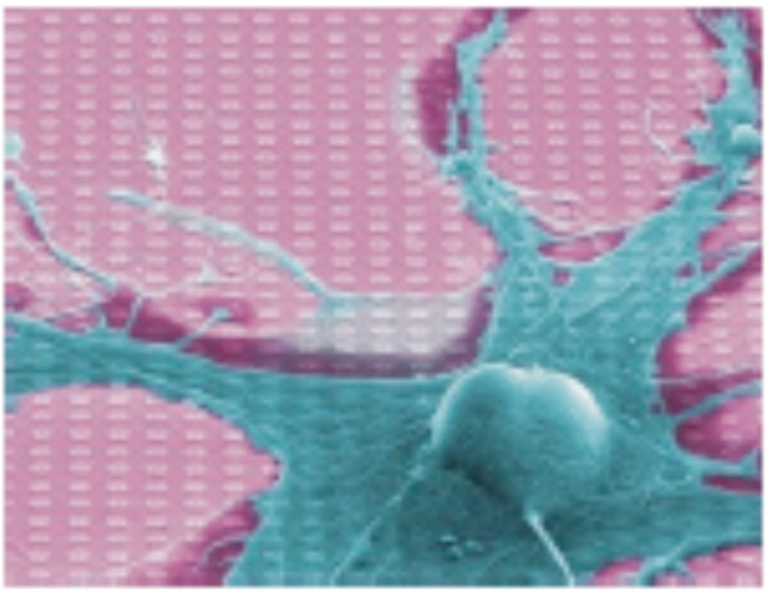
Carbon nanotubes can be used for H fuel storage



Possible entry point for nanomedical device

Health Care: Nerve Tissue Talking to Computers

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



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

FIGURE 1.62

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!

Technology: Building Smaller Devices and Chips

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

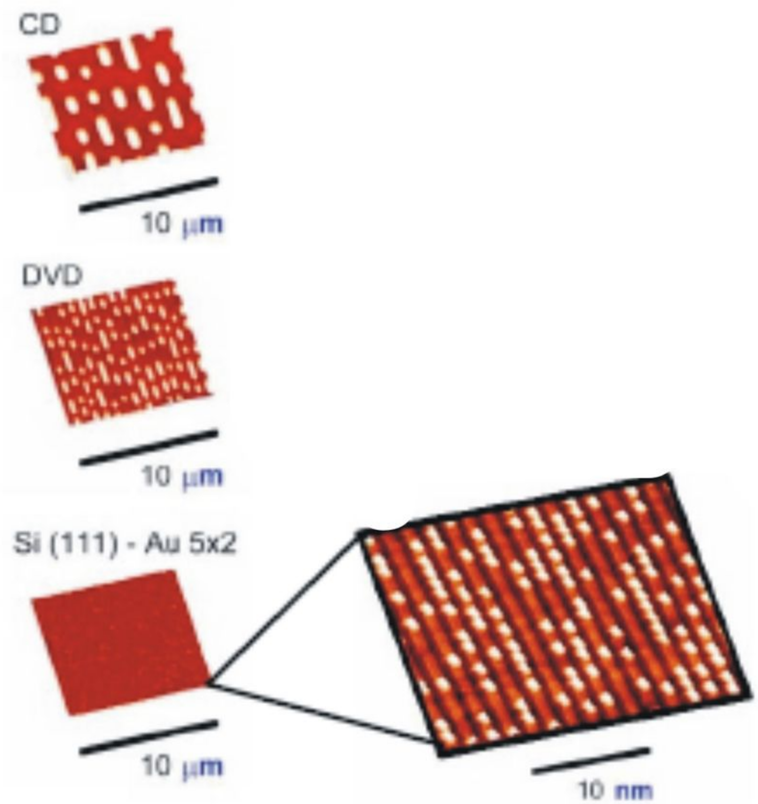
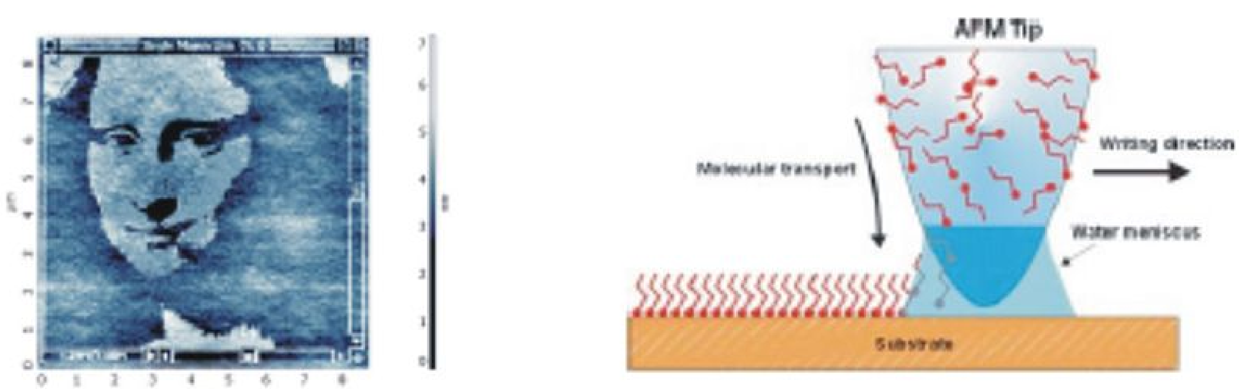


FIGURE 1.63



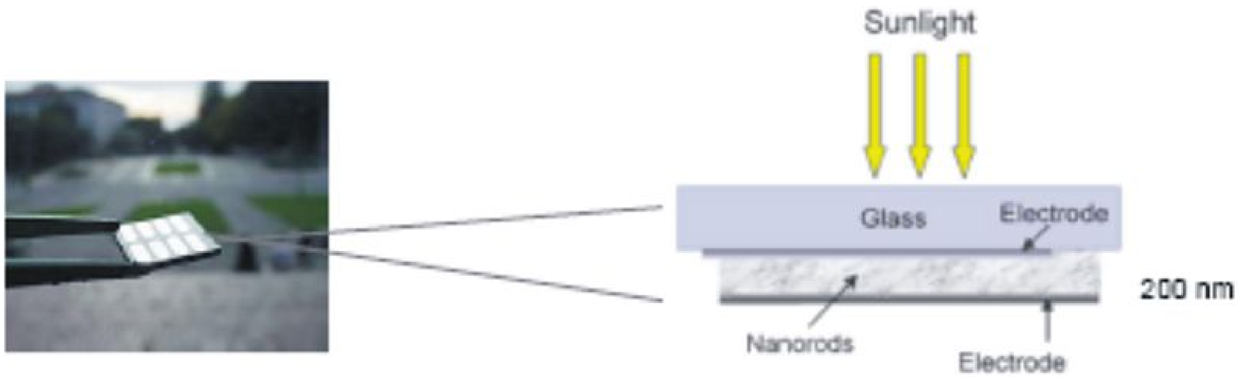
Mona Lisa, 8 microns tall, created by AFM nanolithography

Transporting molecules to a surface by dip-pen nanolithography

FIGURE 1.64

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

FIGURE 1.65

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 microns
  - Bounce light off of surfaces to create images

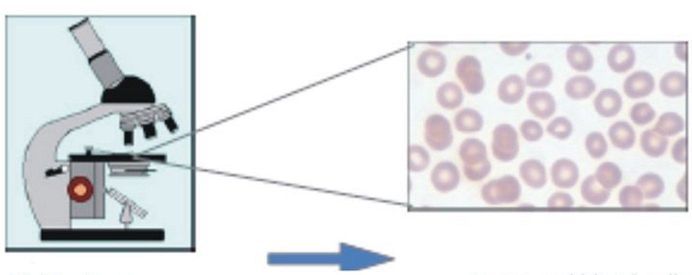
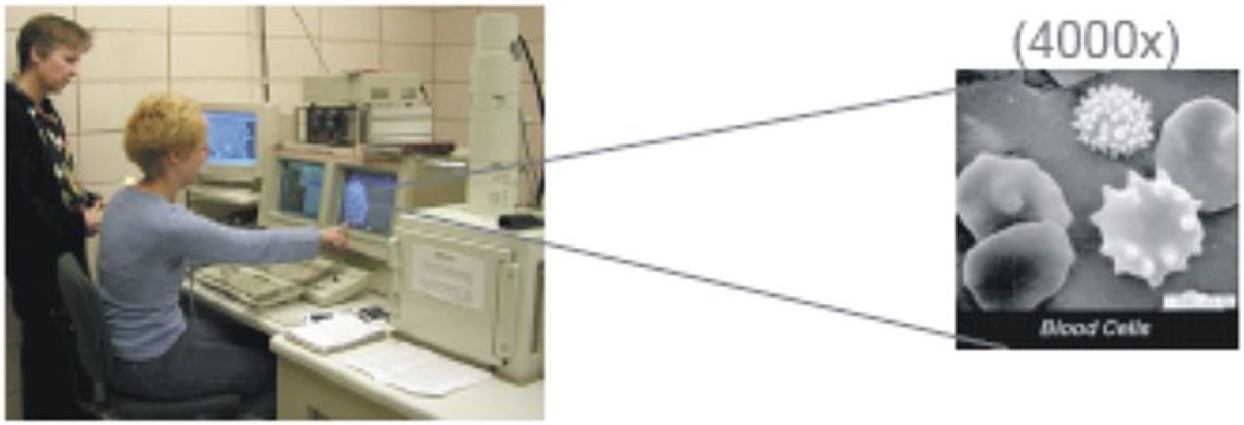


FIGURE 1.66

Using Electrons to See

- Scanning electron microscopes (SEMs), invented in the 1930s, let us see objects as small as 10 nanometers

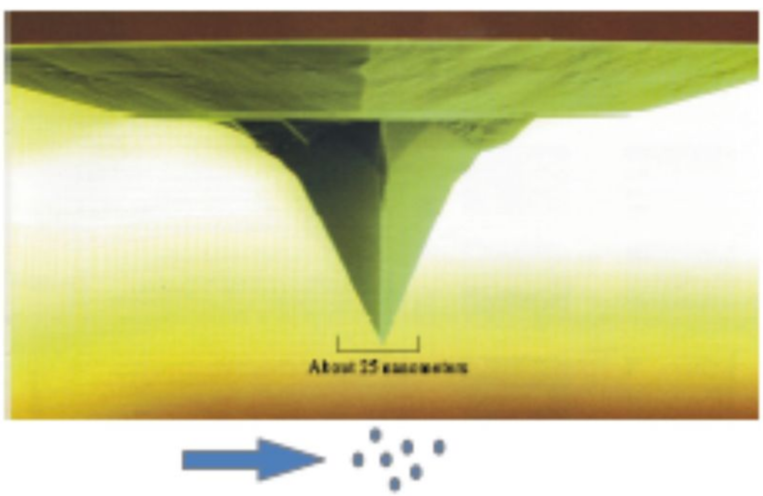
- Bounce **electrons** off of surfaces to create images
- Higher resolution due to small size of electrons



Greater resolution to see things like blood cells in greater detail

FIGURE 1.67

Touching the Surface



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

FIGURE 1.68

- 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!

Size-Dependent Properties

So now that we can [U+0080] [U+009C] see [U+0080] [U+009D] what [U+0080] [U+0099] s going on...

Howdopropertieschangeatthenanoscale?

Properties of a Material

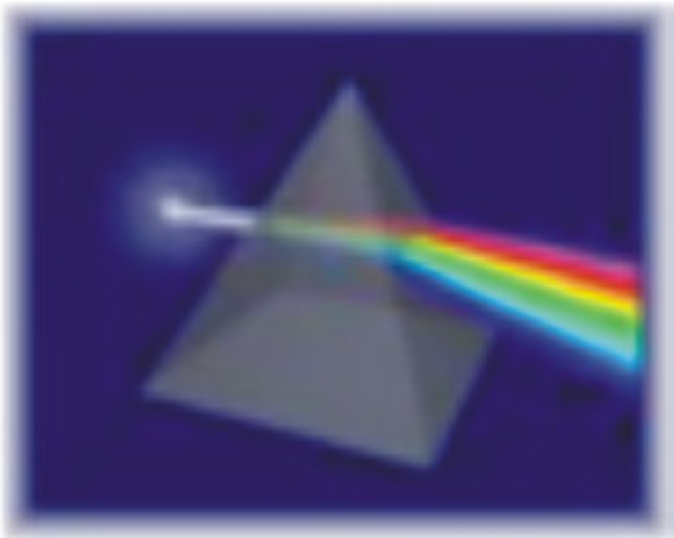
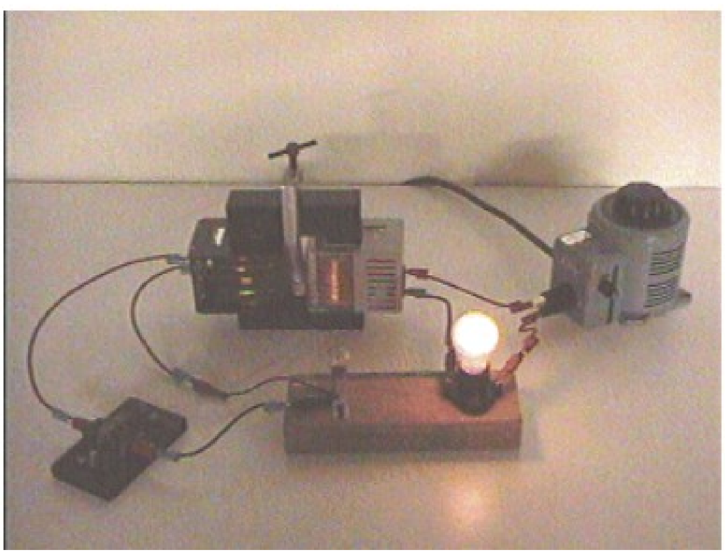


FIGURE 1.69

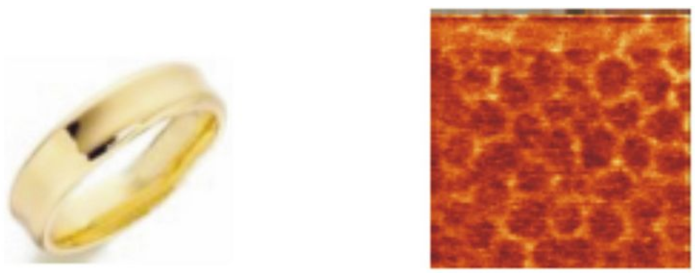


- A property describes how a material acts under certain conditions
- Types of properties
  - Optical (e.g. color, transparency)
  - Electrical (e.g. conductivity)
  - Physical (e.g. hardness, melting point)

   - Chemical (e.g. reactivity, reaction rates)
- Properties are usually measured by looking at large ($\sim 10^{23}$) aggregations of atoms or molecules

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 "Bulk" gold looks yellow particles look red

FIGURE 1.70

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

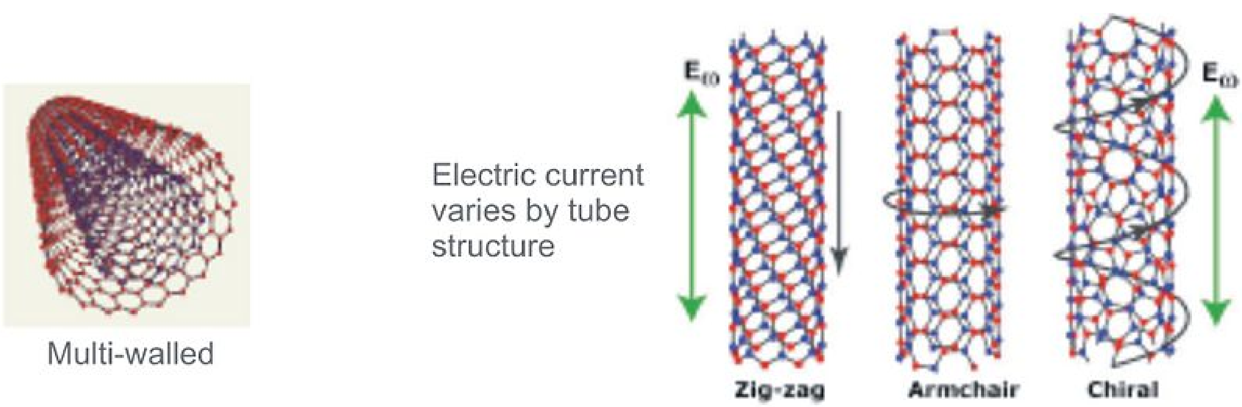


FIGURE 1.71

Physical Properties Change: Melting Point of a Substance

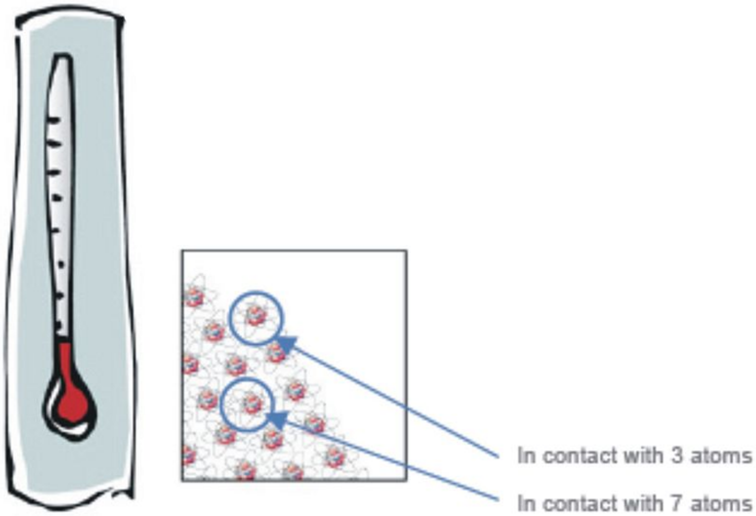
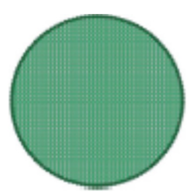
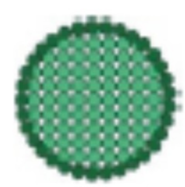


FIGURE 1.72

- 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

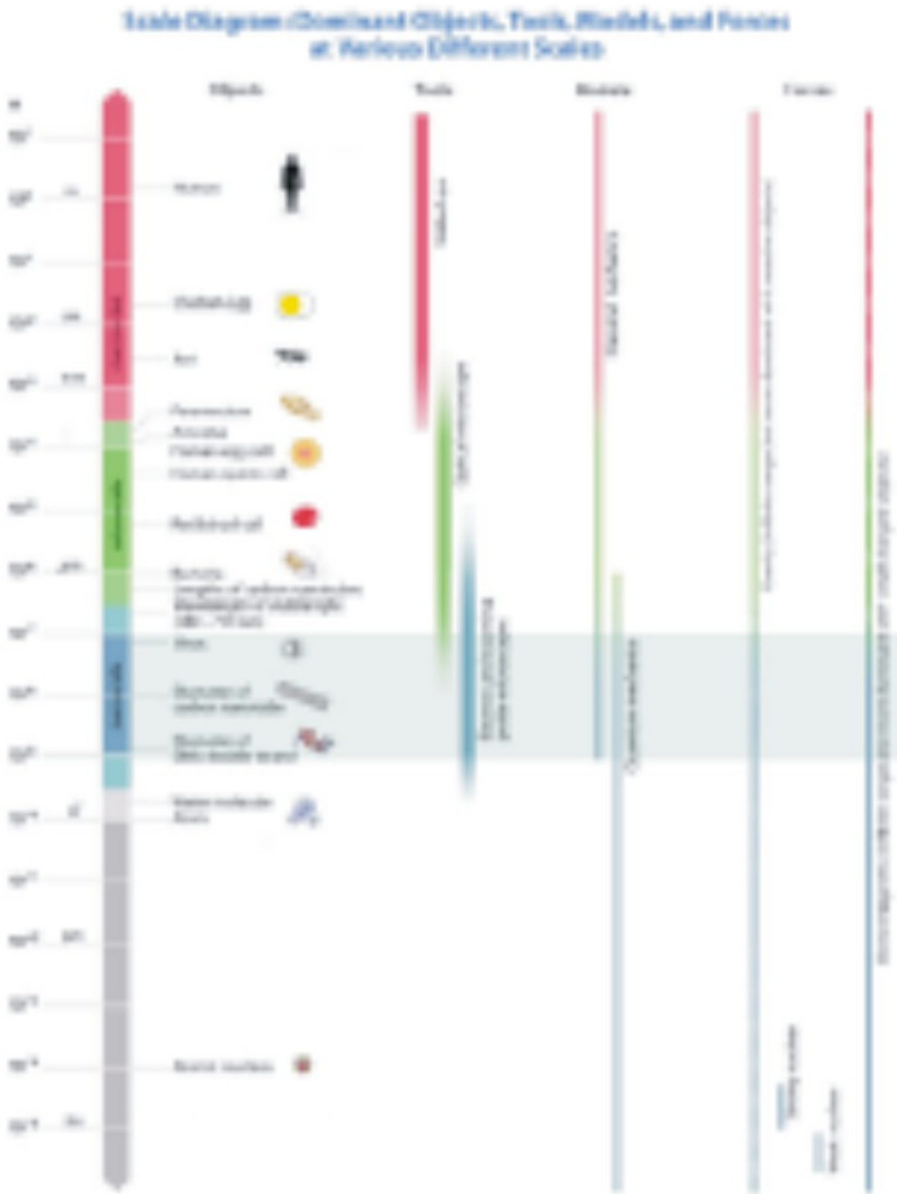
TABLE 1.22: Physical Properties Example: Substance's Melting Point II

	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

Size Dependant Properties

Why do properties change?

Scale Changes Everything



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

Scale Changes Everything II

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

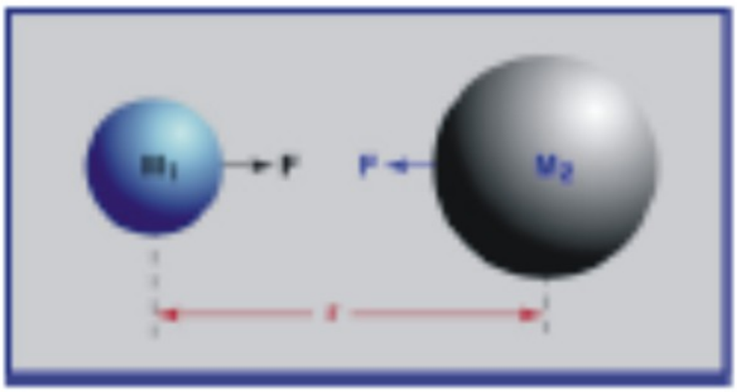
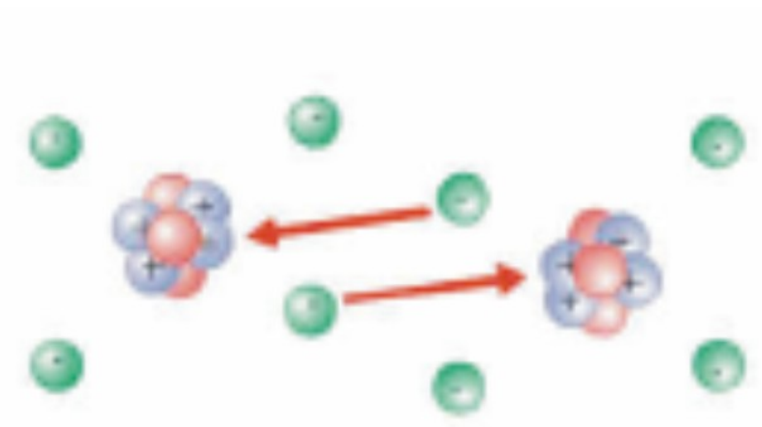


FIGURE 1.73



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!

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

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

Random Molecular Motion is Significant

- Tiny particles (like dust) move about randomly
  - At the macroscale, we barely see movement, or why it moves
  - At the nanoscale, the particle is moving wildly, batted about by smaller particles
- Analogy
  - Imagine a huge (10 meter) balloon being batted about by the crowd in a stadium. From an airplane, you barely see movement or people hitting it; close up you see the balloon moving wildly.

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

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

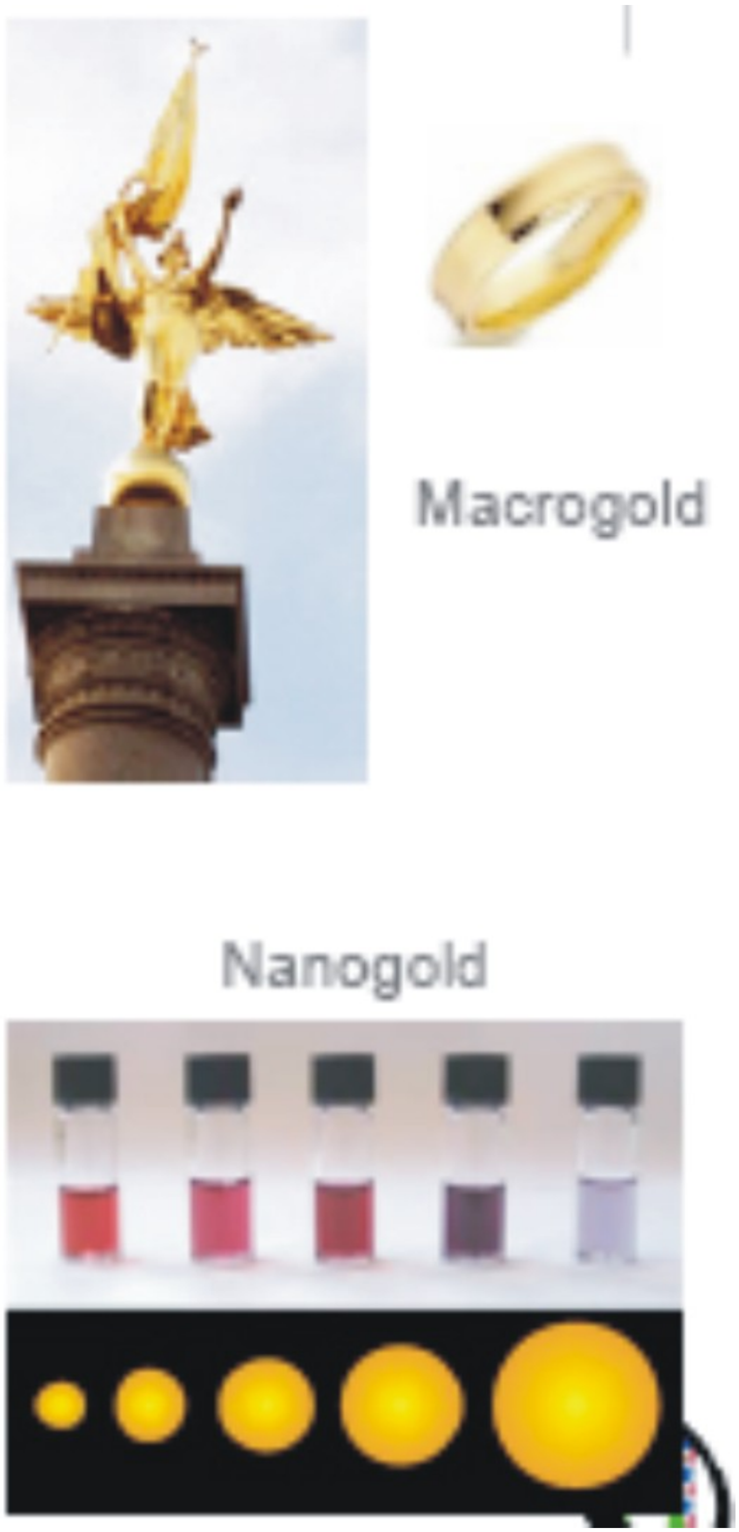


FIGURE 1.74

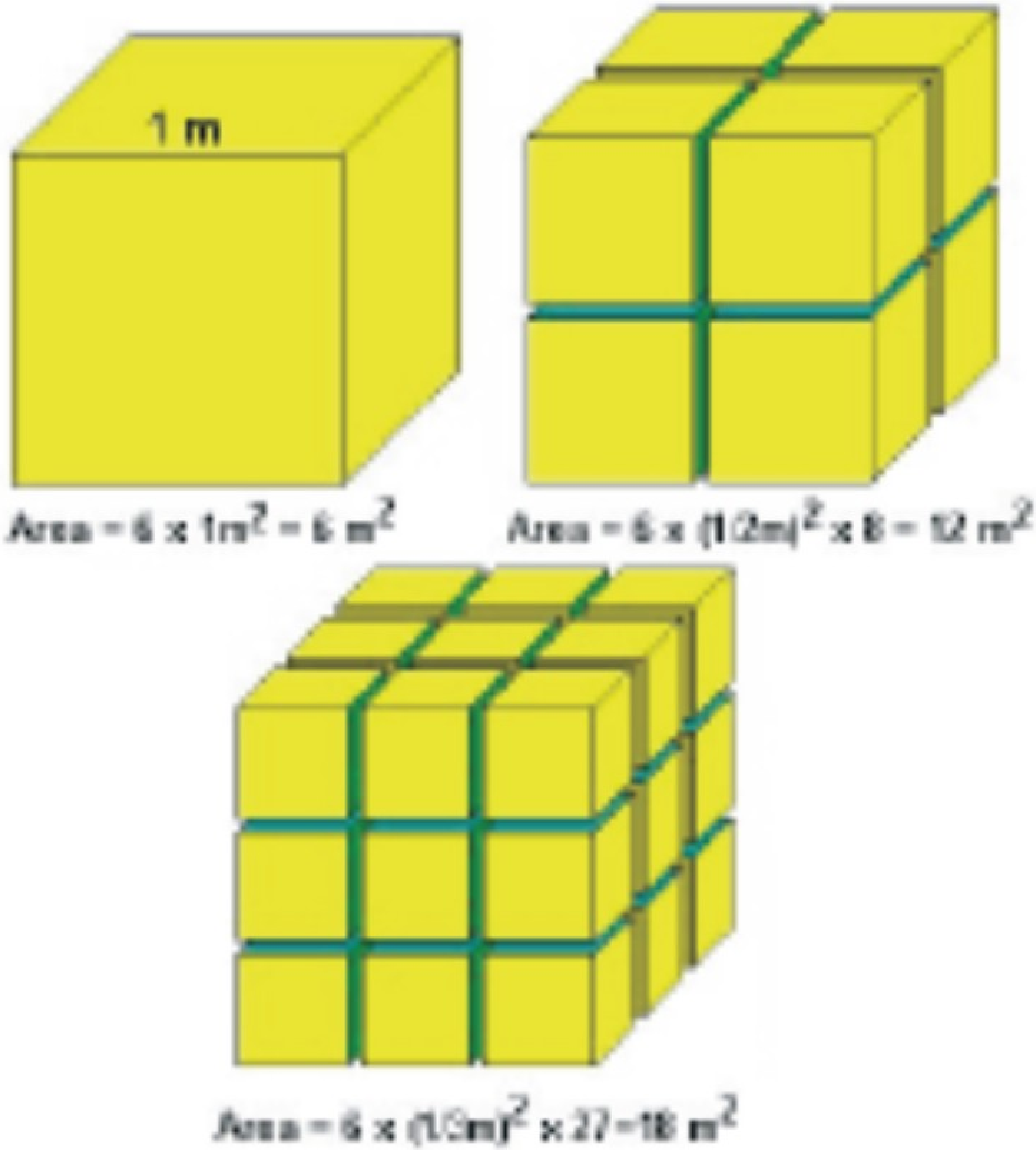
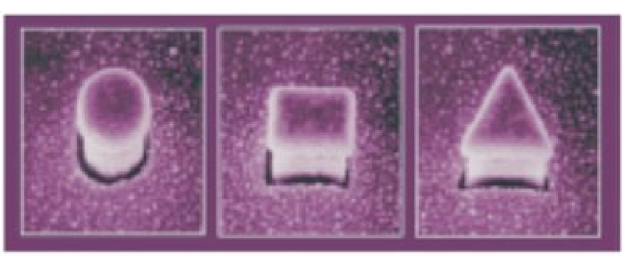
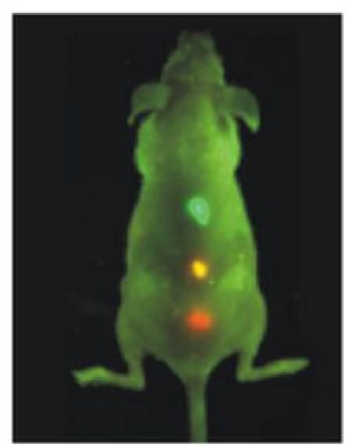


FIGURE 1.75

FIGURE 1.76



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



Early tumor detection, studied in mice

FIGURE 1.77

Cardiac tissue grown with the help of nanofiber filaments

FIGURE 1.78

- Could be used to replace worn out or damaged heart tissue

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

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

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

Potential Risks of Nanotechnology

- Health issues

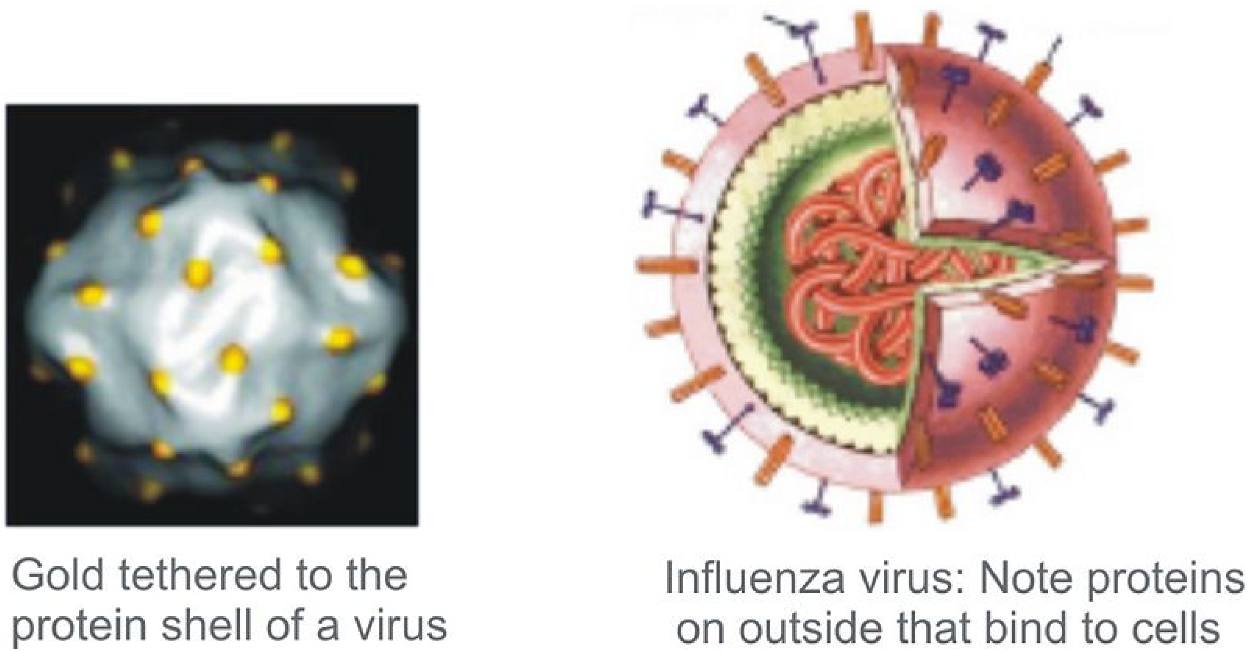


FIGURE 1.79

- 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

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

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

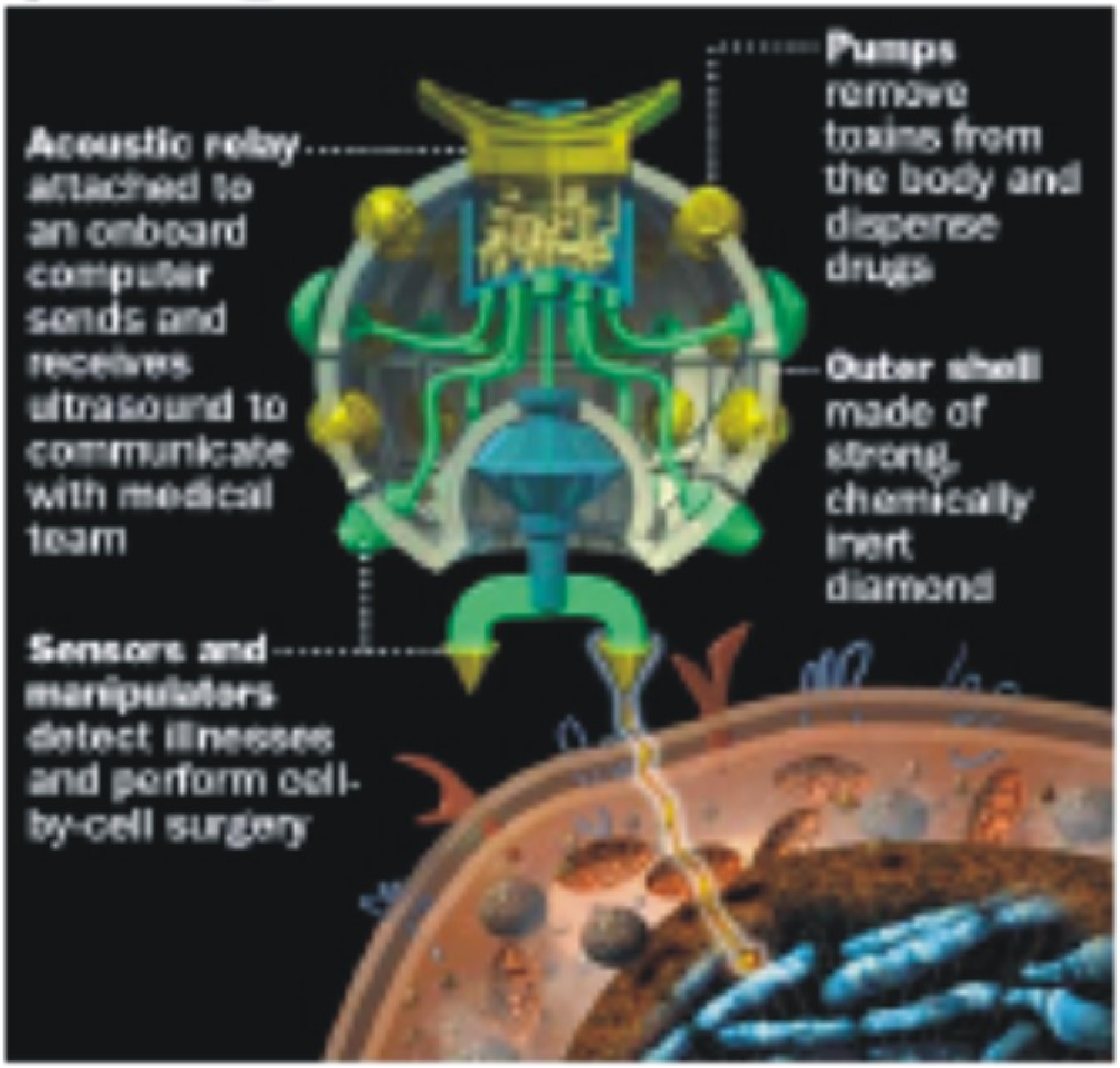
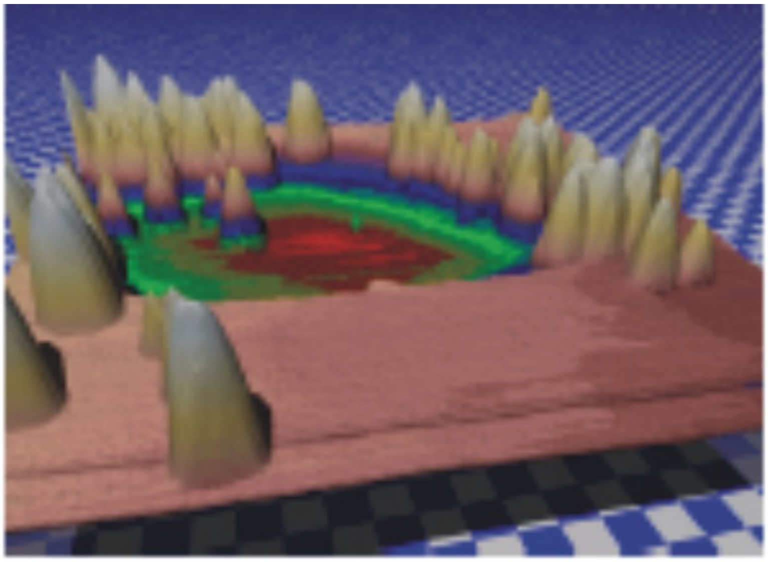

Acoustic relay attached to an onboard computer sends and receives ultrasound to communicate with medical team
Pumps remove toxins from the body and dispense drugs
Outer shell made of strong, chemically inert diamond
Sensors and manipulators detect illnesses and perform cell-by-cell surgery

FIGURE 1.80



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

FIGURE 1.81

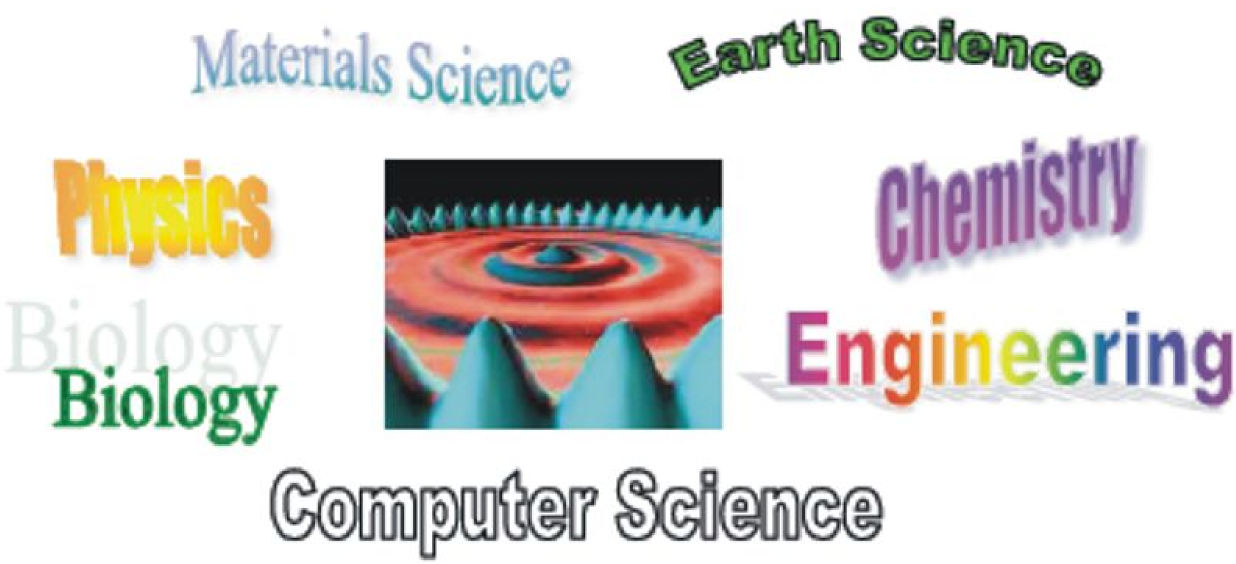


FIGURE 1.82

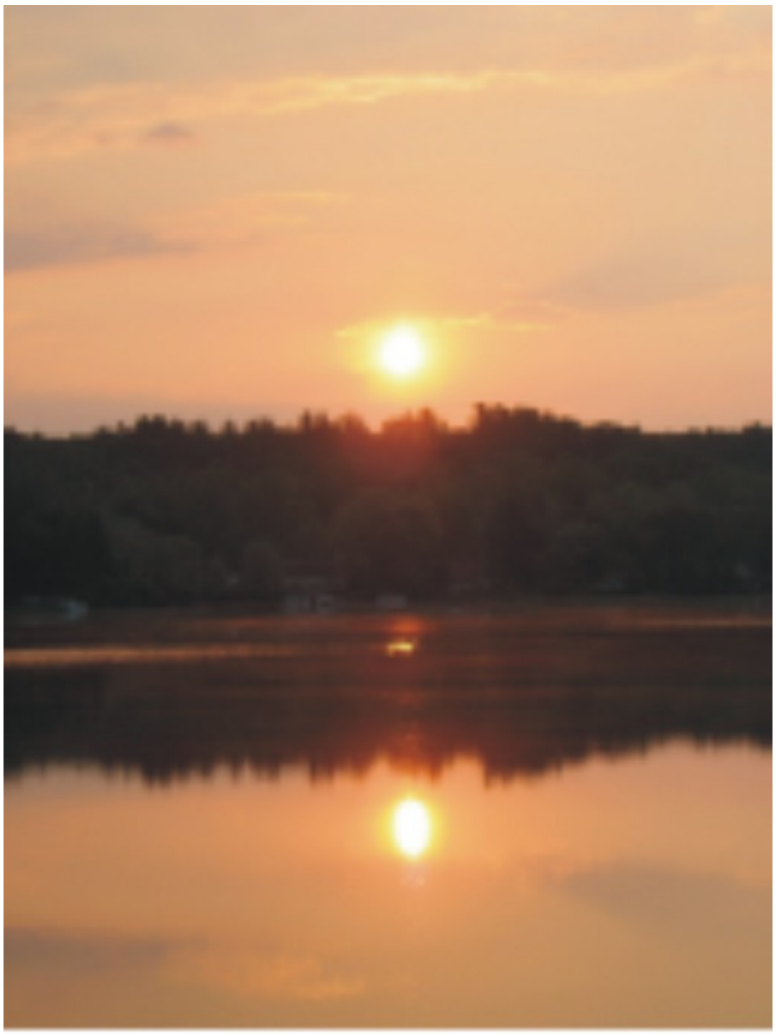


FIGURE 1.83

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/scien 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 manmade 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 128×128 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 Principles/Lithographies/AFM_Oxidation_Lithography_mode37.html http://www.ntmdt 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/8148/8148coun

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_de

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, realworld 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.

Chapter 2 Clear Sunscreen-Teacher Materials

Chapter Outline

2.1 How Light Interacts with Matter

2.1 How Light Interacts with Matter

Unit Overview

Contents

- For Anyone Planning to Teach Nanoscience. . . Read This First!
- Clear Sunscreen Overview, Learning Goals #38; Standards
- Unit at a Glance: Suggested Sequencing of Activities for Full Unit
- Alignment of Unit Activities with Learning Goals
- Alignment of Unit Activities with Curriculum Topics
- List of Sunscreen Products that use Nanoparticle Ingredients
- (Optional) Clear Sunscreen Pretest/Posttest: Teacher Answer Sheet

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 #38; 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 #38; 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., #38; Robbins, M. (2005, June). The breakdown of continuum models for mechanical contacts. *Nature 435,* 929-932.

TABLE 2.1: 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

Clear Sunscreen: Overview, Learning Goals #38; Standards

Type of Courses: Chemistry, Physics

Grade Levels: 9-12

Topic Area: The interaction of light and matter

Key Words: Nanoscience, nanotechnology, light scattering, electromagnetic spectrum, organic compounds, inorganic compounds

Time Frame: 6 class periods (assuming 50 – minutes classes), with extensions available

Overview

Traditional inorganic sunscreens use "large" zinc oxide particles which effectively block the full spectrum of ultraviolet (UV) light, but also scatter visible light, giving the cream an undesirable white color. Because of this, people often apply too little sunscreen or choose another, less effective, kind. If nanosized particles of zinc oxide are used instead, the cream is transparent because the diameter of each nanoparticle is much smaller than the wavelength of visible light and thus does not scatter the light. Given our increased awareness of the dangers of long wave ultraviolet (UVA) light (which many other sunscreens do not block), a full spectrum sunscreen that people are willing to use is an important tool for preventing skin cancer.

Enduring Understandings (EU)

What enduring understandings are desired? Students will understand:

1. How the energies of different wavelengths of light interact differently with different kinds of matter.
2. Why particle size can affect the optical properties of a material.
3. That there may be health issues for nanosized particles that are undetermined at this time.
4. That it is possible to engineer useful materials with an incomplete understanding of their properties.
5. There are often multiple valid theoretical explanations for experimental data; to find out which one works best, additional experiments are required.
6. How to apply their scientific knowledge to be an informed consumer of chemical products.

Essential Questions (EQ)

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

1. What are the most important factors to consider in choosing a sunscreen?
2. How do you know if a sunscreen has “nano” ingredients?
3. How do “nano” sunscreen ingredients differ from most other ingredients currently used in sunscreens?

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 the mechanisms of absorption and scattering by which light interacts with matter.
2. Describe how particle size, concentration and thickness of application affect how particles in a suspension scatter light.
3. Explain how the phenomenon of seeing things in the world is a human visual response depending on how light interacts with objects.
4. Evaluate the relative advantages (strong blockers, UVA protection) and disadvantages (possible carcinogenic effects, not fully researched) of using nanoparticulate sunscreens.

Prerequisite Knowledge

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

1. Atoms, molecules, ionic and covalent compounds
2. Atomic energy levels, absorption of light
3. Light waves, frequencies, electromagnetic spectrum, color

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: (2 of the 5 categories apply)

- Evidence, models and explanation
- Form and function

Grades 9-12 Content Standard A: Science as Inquiry

Abilities Necessary to Do Scientific Inquiry

- **Formulate scientific explanations and models.** Student inquiries should culminate in formulating an explanation or model. Models should be physical, conceptual, and mathematical. In the process of answering the questions, the students should engage in discussions and arguments that result in the revision of their explanations. These discussions should be based on scientific knowledge, the use of logic, and evidence from their investigation. (12ASI1.4.)
- **Analyze alternative explanations.** This aspect of the standard emphasizes the critical abilities of analyzing an argument by reviewing current scientific understanding, weighing the evidence, and examining the logic so as to decide which explanations and models are best. In other words, although there may be several plausible explanations, they do not all have equal weight. Students should be able to use scientific criteria to find the preferred explanations. (12ASI1.5.)

Understandings about Scientific Inquiry

- **Scientific explanations.** Scientific explanations must adhere to criteria such as: a proposed explanation must be logically consistent; it must abide by the rules of evidence; it must be open to questions and possible modification; and it must be based on historical and current scientific knowledge. (12ASI2.5)

Grades 9-12 Content Standard B: Physical Science

Chemical Reactions

- **Energy and chemical reactions.** Chemical reactions may release or consume energy. Some reactions such as the burning of fossil fuels release large amounts of energy by losing heat and by emitting light. Light can initiate many chemical reactions such as photosynthesis and the evolution of urban smog. (12BPS3.2)

Interactions of Energy and Matter

- **Waves**. Waves, including sound and seismic waves, waves on water, and light waves, have energy and can transfer energy when they interact with matter. (12BPS6.1)
- **Electromagnetic waves.** Electromagnetic waves result when a charged object is accelerated or decelerated. Electromagnetic waves include radio waves (the longest wavelength), microwaves, infrared radiation (radiant heat), visible light, ultraviolet radiation, $x-$ rays, and gamma rays. The energy of electromagnetic waves is carried in packets whose magnitude is inversely proportional to the wavelength. (12BPS6.2)
- **Discrete amounts of energy in atoms/molecules.** Each kind of atom or molecule can gain or lose energy only in particular discrete amounts and thus can absorb and emit light only at wavelengths corresponding to these amounts. These wavelengths can be used to identify the substance. (12BPS6.3)

Grades 9-12 Content Standard E: Science and Technology

Understandings about Science and Technology

- **Scientists in different disciplines use different methods.** 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)

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

Personal and Community Health

- **Personal choice concerning fitness and health involves multiple factors.** Personal choice concerning fitness and health involves multiple factors. Personal goals, peer and social pressures, ethnic and religious beliefs, and understanding of biological consequences can all influence decisions about health practices. (12FSPSP1.3)

Science and Technology in Local, National, and Global Challenges

- **Individuals and society must decide on proposals of new research/technologies.** 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

Nature of Scientific Knowledge

- **All scientific knowledge is subject to change as new evidence becomes available.** Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available. The core ideas of science such as the conservation of energy or the laws of motion have been subjected to a wide variety of confirmations and are therefore unlikely to change in the areas in which they have been tested. In areas where data or understanding are incomplete, such as the details of human evolution or questions surrounding global warming, new data may well lead to changes in current ideas or resolve current conflicts. In situations where information is still fragmentary, it is normal for scientific ideas to be incomplete, but this is also where the opportunity for making advances may be greatest. (12GHNS2.3)

Historical Perspectives

- **Scientific knowledge evolves over time, building on earlier knowledge.** The historical perspective of scientific explanations demonstrates how scientific knowledge changes by evolving over time, almost always building on earlier knowledge. (12GHNS3.4)

Unit at a Glance: Suggested Sequencing of Activities

Overview

The Clear Sunscreen Unit has been designed in a modular fashion to allow you maximum flexibility in adapting it to your student's needs. Lessons 1 and 2 provide basic coverage of the dangers of UV exposure, the mechanisms by which sunscreens work and the factors that determine their appearance. Combined with Lesson 5 (culminating activities), they make up the basic sequence for the unit. Lessons 3 and 4 are each extensions of one of the topics covered in lesson 2 (absorption and appearance) and can be added individually to the unit to increase coverage of that topic.

TABLE 2.2:

Lesson	Basic Sequence	Optional Extensions
Lesson 1: Introduction to Sun Protection	√	
Lesson 2: All About Sunscreens	√	
Lesson 3: How Sunscreens Block: The Absorption of UV Light		√

TABLE 2.2: (continued)

Lesson	Basic Sequence	Optional Extensions
Lesson 4: How Sunscreens Appear: Interactions with Visible Light		√
Lesson 5: Culminating Activities	√	

In addition, most lessons contain an interactive presentation and one or more options for activities so you can tailor the depth and duration of the lesson to meet your needs. The following pages contain a suggested sequencing of activities for both the basic and full unit, but of course there are many other combinations possible.

TABLE 2.3: Suggested Sequencing of Activities for Basic Unit

Lesson	Teaching Days	Main Activities and Materials	Learning Goals	Assessment	Homework
Lesson 1: Introduction to Sun Protection	2 days: *Day 1*	Sun Protection: Understanding the Danger PowerPoint and Discussion Initial Ideas: Student Worksheet	EU: 1, 6 KKS: 4	Initial Ideas Worksheet	Read UV Protection Lab Activity and generate hypotheses
	Day 2	UV Protection Lab Activity		UV Protection Activity Worksheet	Finish UV Protection Activity Worksheet
Lesson 2: All About Sunscreens	2 days : *Day 1*	All About Sunscreen PowerPoint and Discussion	EU: 2, 3, 4, 5, 6 KKS: 1, 2, 3, 4		Read Sunscreen Ingredients Activity
	Day 2	Sunscreen Ingredients Activity Reflection on Guiding Questions		Sunscreen Ingredients Activity Worksheet Reflection on Guiding Questions	
Lesson 5: Culminating Activities	2 days: *Day 1*	Consumer Choice Project (Performance Assessment) OR Quiz and Final Reflection on Guiding Questions	EU: 1, 2, 3, 4, 6 KKS: 1, 2, 3, 4	Final Reflections Worksheet Quiz	Prepare to share pamphlets

TABLE 2.3: (continued)

Lesson	Teaching Days	Main Activities and Materials	Learning Goals	Assessment	Homework
	Day 2 (15 min *only for quiz choice*)	Sharing of Consumer Choice Pamphlets and Final Reflection on Guiding Questions OR Return and review of quizzes		Project Scoring Rubric and Peer Feedback Form	

TABLE 2.4: Suggested Sequencing of Activities for Full Unit

Lesson	Teaching Days	Main Activities and Materials	Learning Goals	Assessment	Homework
Lesson 1: Introduction to Sun Protection	2 days: *Day 1*	Sun Protection: Understanding the Danger PowerPoint and Discussion Initial Ideas: Student Worksheet	EU: 1, 6 KKS: 4	Initial Ideas Worksheet	Read UV Protection Lab Activity and generate hypotheses
	Day 2	UV Protection Lab Activity		UV Protection Activity Worksheet	Finish UV Protection Activity Worksheet
Lesson 2: All About Sunscreens	2 days : *Day 1*	All About Sunscreen PowerPoint and Discussion	EU: 2, 3, 4, 5, 6 KKS: 1, 2, 3, 4		Read Sunscreen Ingredients Activity
	Day 2	Sunscreen Ingredients Activity Reflection on Guiding Questions		Sunscreen Ingredients Activity Worksheet Reflection on Guiding Questions	Absorption of Light by Matter: Student Reading
Lesson 3: How Sunscreens Block: The Absorption of UV Light	1 Day	Discussion of Absorption Reading How Sunscreens Block: The Absorption of UV Light PowerPoint and Discussion Reflection on Guiding Questions:	EU: 1 KKS: 1	Reflection on Guiding Questions	Scattering of Light by Suspended Clusters: Student Reading

TABLE 2.4: (continued)

Lesson	Teaching Days	Main Activities and Materials	Learning Goals	Assessment	Homework
Lesson 4: How Sunscreens Appear: Interactions with Visible Light	2-3 days: Day 1	How Sunscreens Appear: Interactions with Visible Light PowerPoint Slides and Discussion Introduction of Sunscreens Animation Activity (creation or viewing pre-made ones)	EU: 1, 2, 6 KKS: 1, 2, 3		Continue to work on animations
	Day 2	Work on Animation Creation OR Discussion of Pre-Made Animations and Reflection on Guiding Questions		Animation worksheet Reflection on Guiding Questions	Prepare to present animations
Lesson 4 (continued)	*Day 3* (*animation creation only*)	Class Presentation and Discussion of Student Animations Reflection on Guiding Questions Reflection of Guiding Questions		Animation Scoring Rubric Reflection on Guiding Questions	
Lesson 5: Culminating Activities	2 days: *Day 1*	Consumer Choice Project (Performance Assessment) OR Quiz and Final Reflection on Guiding Questions	EU: 1, 2, 3, 4, 6 KKS: 1, 2, 3, 4	Final Reflections Worksheet Quiz	Prepare to share pamphlets

TABLE 2.4: (continued)

Lesson	Teaching Days	Main Activities and Materials	Learning Goals	Assessment	Homework
	Day 2 (15 min *only for quiz choice*)	Sharing of Consumer Choice Pamphlets and Final Reflection on Guiding Questions OR Return and review of quizzes		Project Scoring Rubric and Peer Feedback Form	

TABLE 2.5:

What **enduring understandings (EU)** are desired? Students will understand:	What **essential questions (EQ)** will guide this unit and focus teaching and learning?	What **key knowledge and skills (KKS)** will students acquire as a result of this unit? Students will be able to:
• How the energies of different wavelengths of light interact differently with our skin and vision.	• How do "nano-sunscreens" differ from traditional sunscreens?	• Describe the mechanism of absorption and scattering by which light interacts with matter.
• Why particle size can affect the optical properties of a material.	• What is the best kind of sunscreen to use and why?	• Describe how particle size, concentration and chemical / solvent identity (refractive index), affect how particles in a suspension scatter light.
• That there may be health issues for nanosized particles that are undetermined at this time.	• Should nanoproducts have special regulations associated with them?	• Explain how the phenomenon of seeing things in the world is a human visual response depending on how light interacts with these objects.
• That it is possible to engineer useful materials with an incomplete understanding of their properties.		• Evaluate the relative advantages (strong blockers, UVA protection) and disadvantages (possible carcinogenic effects, not fully researched) of using nanoparticulate sunscreens

TABLE 2.5: (continued)

What **enduring understandings (EU)** are desired? Students will understand:	What **essential questions (EQ)** will guide this unit and focus teaching and learning?	What **key knowledge and skills (KKS)** will students acquire as a result of this unit? Students will be able to:
• There are often multiple valid theoretical explanations for experimental data; to find out which one works best, additional experiments are required.		
• How to apply their scientific knowledge to be an informed consumer of chemical products.		

Alignment of Unit Activities with Learning Goals

TABLE 2.6:

		Lesson 1	Lesson 2	Lesson 3	Lesson 4	Lesson 5
	Presentation	*UV Dangers*	*All About Sunscreens*	*Absorption*	*Appearance*	
	Activity	*UV Protection Lab Activity*	*Sunscreen Label Activity*	*Student Reading*	*Animation Activity*	*Consumer Choice Project*
Learning Goals	**Assessment**	*Lab Results/ Initial Ideas Worksheet*	*Label Results/ Reflection Worksheet*	*Reflection Worksheet*	*Animation/ Reflection Worksheet*	*Consumer Pamphlets/ Quiz*
Students will understand...						
EU 1. How the energies of different wavelengths of light interact differently with different kinds of matter.		•		•	•	•

TABLE 2.6: (continued)

	Lesson 1	Lesson 2	Lesson 3	Lesson 4	Lesson 5
EU 2. Why particle size can affect the optical properties of a material.		•		•	•
EU 3. That there may be health issues for nanosized particles that are undetermined at this time.		•			•
EU 4. That it is possible to engineer useful materials with an incomplete understanding of their properties.		•			•
EU 5. There are often multiple valid theoretical explanations for experimental data; to find out which one work best, additional experiments are required.		•			
EU6. How to apply their scientific knowledge to be an informed consumer of chemical products.	•	•		•	•

TABLE 2.7:

		Lesson 1	Lesson 2	Lesson 3	Lesson 4	Lesson 5
	Presentation	*UV Dangers*	*All About Sunscreens*	*Absorption*	*Appearance*	
	Activity	*UV Protection Lab Activity*	*Sunscreen Label Activity*	*Student Reading*	*Animation Activity*	*Consumer Choice Project*
Learning Goals	**Assessment**	*Lab Results/ Initial Ideas Worksheet*	*Label Results/ Reflection Worksheet*	*Reflection Worksheet*	*Animation/ Reflection Worksheet*	*Consumer Pamphlets/ Quiz*
Students will able to...						
KKS1. Describe the mechanism of absorption and scattering by which light interacts with matter			•	•	•	•
KKS2. Describe how particle size, concentration and thickness of application affect how particles in a suspension scatter light.			•		•	•
KKS3. Explain how the phenomenon of seeing things in the world is a human visual response depending on how light interacts with objects.			•		•	•

TABLE 2.7: (continued)

	Lesson 1	Lesson 2	Lesson 3	Lesson 4	Lesson 5
KKS4. Evaluate the relative advantages (strong blockers, UVA protection) and disadvantages (possible carcinogenic effects, not fully researched) of using nanoparticulate sunscreens	•	•			•

Alignment of Unit Activities with Curriculum Topics

TABLE 2.8: (continued)

Unit Topic	Chapter Topic	Subtopic	Clear Sunscreen Lessons	Specific Materials

TABLE 2.8: **Chemistry**

Unit Topic	Chapter Topic	Subtopic	Clear Sunscreen Lessons	Specific Materials
Structure of Matter	Electron Configuration	Radiant Energy	• Lesson 1 (L1): Introduction to Sun Protection • Lesson 2 (L2): All about Sunscreens • Lesson 4 (L4): How sunscreens appear: scattering • Lesson 5 (L5): culminating activities	**Slides** • L1: 1-14 (15-17 optional) • L2: 2, 16-25 • L4: All Slides **Activity/Handout** • L1 – UV Protection Lab Activity – Summary of Sun Radiation • L2 – Light Scattering by 3 Sunscreens handout – Sunscreen Ingredient Activity – FDA Approved Sunscreen Ingredients • L4 – Reading: Scattering of Light by Particles – Ad Cam-

TABLE 2.8: (continued)

Unit Topic	Chapter Topic	Subtopic	Clear Sunscreen Lessons	Specific Materials
Structure of Matter	Electron Configuration	Quantum Theory	• Lesson 3 (L3): How sunscreens block: absorption	**Slides** • L2: 8 • L3: All Slides • L4: 8, 9
Chemistry of our World	Carbon Compounds	Organic Chemistry	• Lesson 2 (L2): All About Sunscreens • Lesson 3 (L3): Absorption	**Slides** • L2: 5-10 • L3: 5-9 **Activity/Handout** • L2: Summary of FDA Approved Sunscreen Ingredients

TABLE 2.9: Physics

Mechanics	Potential Energy and Conservation of Energy	Absorption Dispersion/scattering	• Lesson 2 (L2): All About Sunscreens • Lesson 3 (L3): The Science Behind Sunscreen Protection: Absorption • Lesson 4 (L4): The Science Behind Sunscreen Appearance: Scattering	**Slides** • L2: 8-10, 14, 18-24 • L3: (most) • L4: (most) **Activity** • Sunscreen Animation
Atomic Physic	Atomic Models	Electromagnetic spectrum Frequency/ wavelength	• Lesson 1 (L1): Intro to Sun Protection	**Slides** • L1: 7
Electricity and Magnetism	Electromagnetic Waves	Photoelectric effect $E = hf$; energy levels	• Lesson 3 (L3): The Science Behind Sunscreen Protection: Absorption • Lesson 4 (L4): The Science Behind Sunscreen Appearance: Scattering	**Slides** • L3: 3, 6-7, 14 • L4: 5, 8

TABLE 2.10: (continued)

Unit Topic	Chapter Topic	Subtopic	Clear Sunscreen Lessons	Specific Materials

TABLE 2.10: **Environmental Science**

Unit Topic	Chapter Topic	Subtopic	Clear Sunscreen Lessons	Specific Materials
Atmosphere and Climate Energy	The Ozone Shield	The Ozone Hole: The Effects of Ozone Thinning	• Lesson 1 (L1): Intro to Sun Protection • Lesson 2 (L2): All About Sunscreens • Lesson 3 (L3): How Sunscreens Block: Absorption • Lesson 4 (L4): How Sunscreen Appear: Scattering • Lesson 5 (L5): Ad Campaign Project	**Slides** • L1-L4: All slides **Activity/Handout** • L1: UV Bead Lab • L2: – Sunscreen ingredients Activity – Light Scattering by Three Sunscreens – Reflection on the Guiding Questions • L3: – Reading: Absorption of Light by Matter – Reflecting on the Guiding Questions • L4: – Reading: Scattering of Light by Particles

TABLE 2.10: (continued)

Unit Topic	Chapter Topic	Subtopic	Clear Lessons	Sunscreen	Specific Materials

TABLE 2.11: (continued)

Unit Topic	Chapter Topic	Subtopic	Clear Sunscreen Lessons	Specific Materials

TABLE 2.11: **Biology**

Unit Topic	Chapter Topic	Subtopic	Clear Sunscreen Lessons	Specific Materials
The Human Body	Skeletal, Muscular, and Integumentary System	The Integumentary System	• Lesson 1 (L1): Intro to Sun Protection • Lesson 2 (L2): All About Sunscreens • Lesson 3 (L3): How Sunscreens Block: Absorption • Lesson 4 (L4): How Sunscreen Appear: Scattering • Lesson 5 (L5): Culminating Activities (Optional)	**Slides** • L1, L2, L4: All slides • *L3: Use with instructor's discretion [1]* **Activity/Handout** • L1: UV Bead Lab • L2: – Sunscreen Ingredients Activity – Light Scattering by Three Sunscreens – Reflections on the Guiding Questions • *L3: Use with instructor's discretion [1]* • L4: – Reading: Scattering of Light Particles – Sunscreens & Sunlight Animations – Ad Cam

TABLE 2.11: (continued)

Unit Topic	Chapter Topic	Subtopic	Clear Lessons	Sunscreen	Specific Materials

[1] Clear Sunscreen Lesson 3 requires some schema of chemistry and physics and can be used with biology students but this is at the instructor's discretion. Instructor should gauge student's depth of understanding behind the chemistry and physics concepts used in this particular lesson.

(All Sunscreens listed as: Brand – Products)

Sunscreens that use nanoparticulate ZnO and/or TiO_2 as their only active ingredients:

- Alba Botanica - Sun (sold at Trader Joes)
- Clinique - Super City Block
- Fallene - Total Block Suncare Line
- Peter Thomas Roth - Ultra-Lite Titanium Dioxide Sunblock
- Blue Lizard - Sensitive Sunscreen
- SkinCeuticals - Daily Sun Defense
- Team Estrogen - All Terrain TerraSport Sunblock
- SunSmart – Therapeutics Line
- Wet Dreams – All Natural Sunscreen Line (Australian Surf Brand)

Sunscreens that use nanoparticulate ZnO and/or TiO_2 as one of their active ingredients along with organic ingredients:

- Dermatone – All products
- Banana Boat - "Surf" and Sensitive Skin Sunscreens
- Long's - Ski #38; Surf Sunscreen
- BullFrog – SPF 45
- Banana Boat – BabyMagic and Kids Sunscreen
- Coppertone - Spectra 3
- No Ad – Kids Sunblock
- Panama Jack - Surf' *N* Sport Clear Zinc

Clear Sunscreen Pretest/Posttest: Teacher Answer Sheet

20 **points total**

1. In what ways are "nano" sunscreen ingredients similar and different from other ingredients currently used in sunscreens? For each of the four categories below, indicate whether "nano" sunscreen ingredients are "similar" or "different" to organic and inorganic ingredients and explain how. (1.5 points each, total of 12 points)

TABLE 2.12:

	Organic Ingredients (e.g. PABA)	Inorganic Ingredients (e.g. Classic Zinc Oxide used by lifeguards)
Chemical Structure	Similar or **Different** How: Nano ingredients are small ionic clusters while organic ingredients are molecules.	**Similar** or Different How: Nano ingredients are a kind of inorganic ingredients. Bother are ionic clusters but the nano clusters are smaller.
Kinds of Light Blocked	Similar or **Different**	**Similar** or Different

TABLE 2.12: (continued)

	Organic Ingredients (e.g. PABA)	Inorganic Ingredients (e.g. Classic Zinc Oxide used by lifeguards)
	How: Organic ingredients each block a small part of the UV spectrum (generally UVB) while nano ingredients block almost the whole thing,	How: Both nano ingredients and traditional inorganic ingredients block almost the whole UV spectrum.
Way Light is Blocked	**Similar** or Different How: Both nano and organic ingredients block UV light via absorption. (The specific absorption mechanism is different, but students are not expected to report this)	**Similar** or Different How: Both nano and inorganic ingredients block UV light via absorption.
Appearance on the Skin	**Similar** or Different How: Both nano and organic ingredients appear clear on the skin.	Similar or **Different** How: Traditional inorganic ingredients appear white on the skin while nano ingredients appear clear.

2. Briefly describe one benefit and one drawback of using a sunscreen that contains "nano" ingredients: (1 point each, a total of 2 points)

Benefits:

- Block whole UV spectrum
- Appear clear, people less likely to underapply

Drawbacks:

- New chemicals not fully studied; possible harmful effects still unknown. FDA is not treating nano-versions of known chemicals as new; needed health studies may not occur.
- Very small particles are more likely to cross membranes and get into unintended parts of the body

3. What determines if a sunscreen appears white or clear on your skin? (4 points)

Answer:

- Particle size.

Explanation:

- Particles whose diameters are $\approx 1/2\ \lambda$ are most likely to scatter light of that wavelength.
- Since visible light has $\lambda \approx 400-800$ nm , particles with a diameter of $200-400$ nm (traditional inorganic ingredients) scatter visible light the most. The scattered rays that are reflected towards our eyes are of all colors in the spectrum, making the sunscreen appear white.
- Particles smaller than 100 nm in diameter (nano and organic ingredients) do not scatter light appreciably. The sunlight passes through them and reaches our skin where the blue/green wavelengths are absorbed. The red/orange/yellow wavelengths are reflected towards our eyes making the skin appear its characteristic color.

4. How do you know if a sunscreen has "nano" ingredients? (2 points)

Ingredients list contains inorganic ingredients (zinc oxide or titanium dioxide) and sunscreen appears clear on the skin.

Introduction to Sun Protection

Contents

- Introduction to Sun Protection: Teacher Lesson Plan
- Sun Protection: Understanding the Danger: PowerPoint with Teacher Notes
- Clear Sunscreen Initial Ideas: Teacher Instructions
- Ultra-Violet (UV) Protection Lab Activity: Teacher Instructions #38; Answer Key

Teacher Lesson Plan

Orientation

This lesson is an introduction to the context and need for sunscreen and the important health concerns it is designed to address. The goal is to spark students' interest by addressing a topic of personal significance and get them to draw on their existing knowledge to generate initial ideas about the driving questions of the unit. They will refine this understanding over the course of the unit and have a chance to reflect on their initial thoughts at the end of the unit.

- The Sun Protection: Understanding the Danger PowerPoint slide set explains the danger of skin cancer and the need to use sunscreen to protect our bodies. A brief introduction to the different kinds of electromagnetic waves and their energies sets the stage for differentiating between the two kinds of UV light from which we need to protect our bodies (UVA and UVB). The final slide in the set introduces the driving questions for the unit.
- The Summary of Radiation Emitted by the Sun: Student Handout is a useful tool for students to refer to throughout the unit to remind them of the key differences between radiation types.
- The Initial Ideas Worksheet gives students the chance to draw on their existing knowledge to formulate first thoughts about the unit. This is a great tool for eliciting students' prior knowledge (and possible misconceptions) related to the unit topics.
- The Ultra-Violet (UV) Protection Lab Activity gives students the chance to explore UV protection first hand by testing the strength of different kinds of blocking substances (for example sunscreens and tee-shirts) with UV sensitive beads.

Essential Questions (EQ)

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

1. What are the most important factors to consider in choosing a sunscreen?
2. How do you know if a sunscreen has "nano" ingredients?
3. How do "nano" sunscreen ingredients differ from most other ingredients currently used in sunscreens?

Enduring Understandings (EU)

Students will understand:

(Numbers correspond to learning goals overview document)

1. How the energies of different wavelengths of light interact differently with different kinds of matter.

6. How to apply their scientific knowledge to be an informed consumer of chemical products

Key Knowledge and Skills (KKS)

Students will be able to:

(*Numbers correspond to learning goals overview document*)

4. Evaluate the relative advantages (strong blockers, UVA protection) and disadvantages (possible carcinogenic effects, not fully researched) of using nanoparticulate sunscreens.

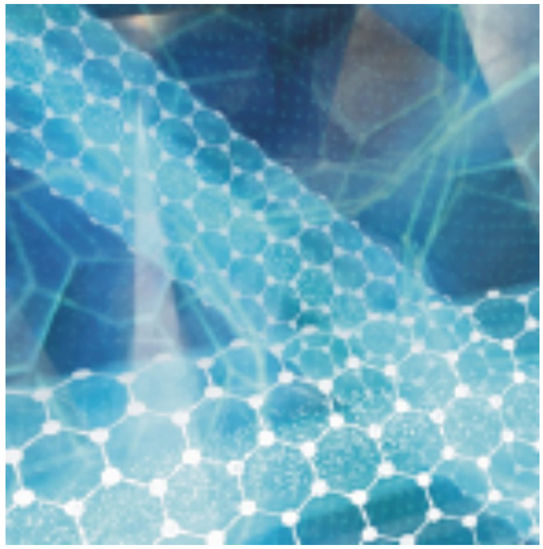
TABLE 2.13: Introduction #38; Initial Ideas Timeline

Day	Activity	Time	Materials
Day 1 (50 min)	Show the Sun Protection: Understanding the Danger PowerPoint Slides, using the embedded question slides and teacher's notes to start class discussion. At the end of the presentation, hand out the Summary of Radiation Emitted by the Sun for students to refer to throughout the unit.	30 min	Sun Protection: Understanding the Danger PowerPoint Slides & Teacher Notes Computer and projector Copies of Summary of Radiation Emitted by the Sun: Student Handout
	Hand out the Clear Sunscreen Initial Ideas: Student Worksheet and have students work alone or in pairs to brainstorm answers to the driving questions. Let students know that at this point they are just brainstorming ideas and they are not expected to be able to fully answer the questions.	10 min	Copies of Clear Sunscreen Initial Ideas: Student Worksheet Clear Sunscreen Initial Ideas: Teacher Instructions
	Return to whole class discussion and have students share their ideas with the class to make a "master list" of initial ideas. The goal is not only to have students get their ideas out in the open, but also to have them practice evaluating how confident they are in their answers. This is also a good opportunity for you to identify any misconceptions that students may have to address throughout the unit.	10 min	

TABLE 2.13: (continued)

Day	Activity	Time	Materials
	Student Homework: Read the UV Protection Lab Activity: Student Instructions & Worksheet and fill in the Hypothesis section.	15 min	Copies of UV Protection Lab Activity: Student Instructions & Worksheet
Day 2 (50 min)	Ask if students have any questions about the lab. Have the students share their hypotheses and the rationales behind them.	10 min	UV Protection Lab Activity: Teacher Instructions & Answer Key
	Have students work through the lab in teams of 2 or 3 . After students have completed the data collection, they should work on the analysis section in their teams.	30 min	Lab Materials (as listed in the UV Protection Lab Activity: Teacher Instructions & Answer Key) *Note that some materials may need to be ordered ahead of time*
	Have students share their analysis graphs with the whole class. Discuss the different results of the different groups and possible explanations for the results found.	10 min	
	If there is time, combine the whole class's data into one super graph.		
	Student Homework: Complete the Conclusion section of the lab	30 min	

Sun Protection



Understanding the Danger

Why use sunscreen?

Too Much Sun Exposure is Bad for Your Body

- Premature skin aging (wrinkles)
- Sunburns
- Skin cancer
- Cataracts

Skin Cancer Rates are Rising Fast

Skin cancer:

- $\sim$ 50% of all cancer cases
- $>$ 1 million cases each year
- $\sim$ 1 person dies every hour

Causes of the increase:

- Decrease ozone protection
- Increased time in the sun
- Increased use of tanning beds

(*Sources:* http://www.msnbc.msn.com/id/8379291/site/newsweek/ http://www.skincarephysicians.com/skincancernet/whatis.htm http://www.msu.edu/ aslocum/sun/skincancer.htm)

What are sun rays?

How are they doing damage?

The Electromagnetic Spectrum

- Sun rays are electromagnetic waves
  - Each kind has a wavelength, frequency and energy

The Sun's Radiation Spectrum I

FIGURE 2.1

FIGURE 2.2

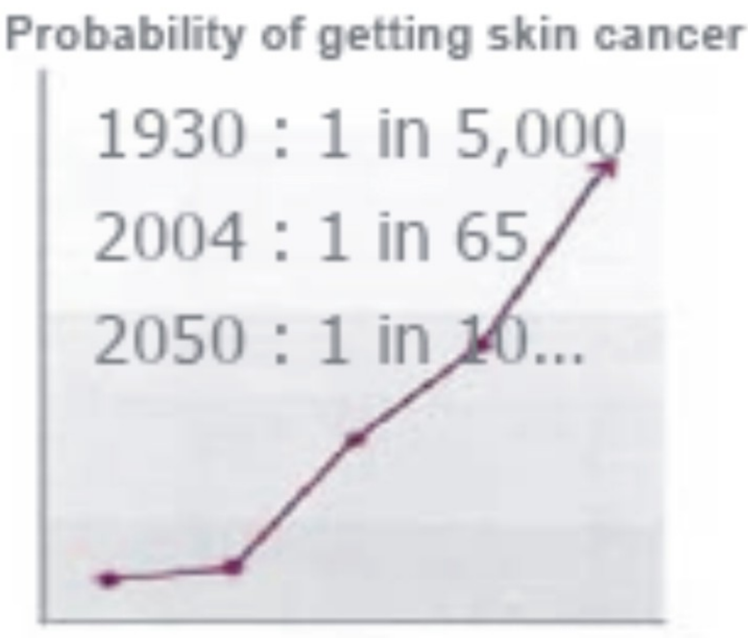

Probability of getting skin cancer
1930 : 1 in 5,000
2004 : 1 in 65
2050 : 1 in 10...

FIGURE 2.3

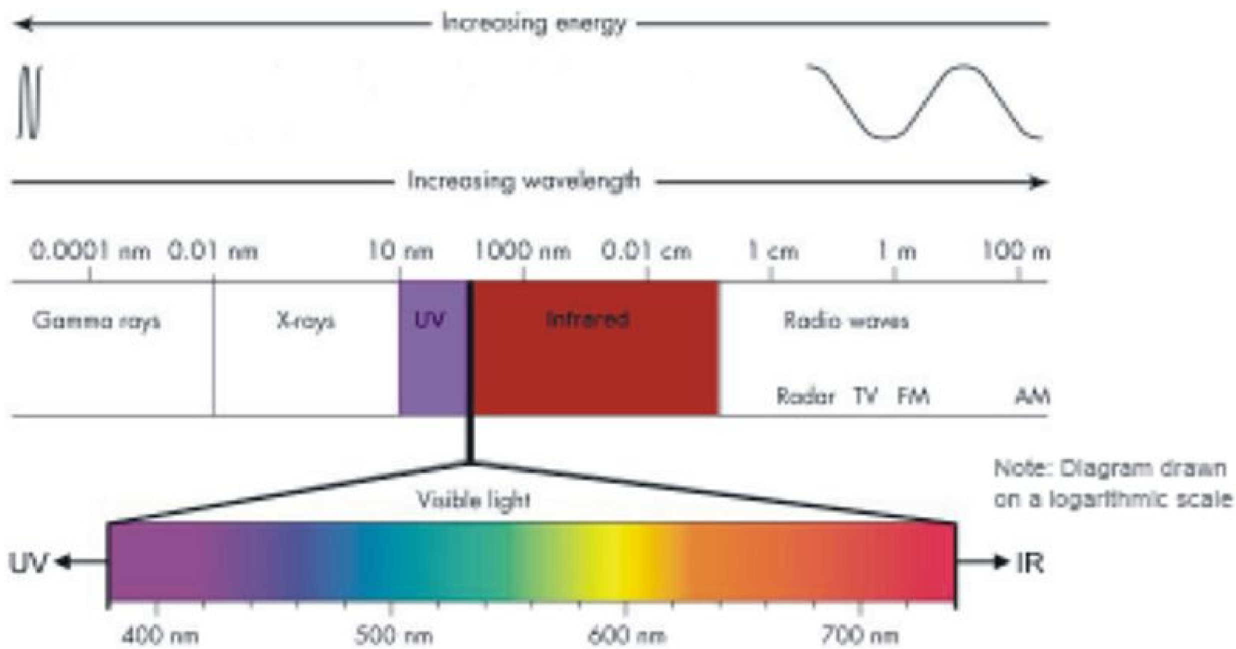


FIGURE 2.4

- The sun emits several kinds of electromagnetic radiation
    - Infrared (IR), Visible (Vis), and Ultra Violet (UV)

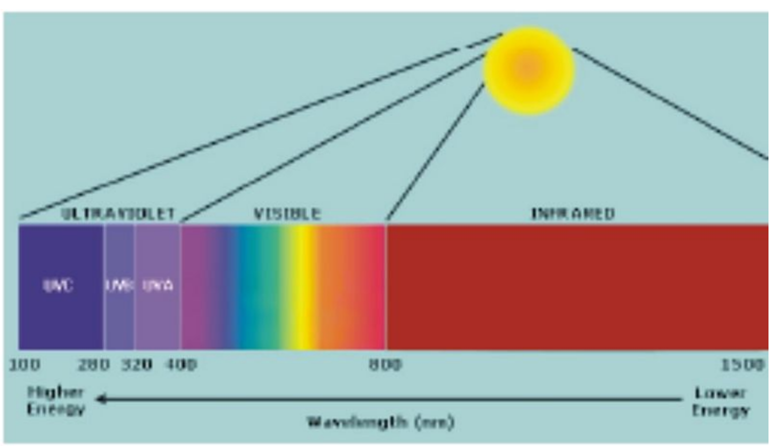


FIGURE 2.5

- Higher energy radiation can damage our skin

The Sun's Radiation Spectrum II

- How much UV, Vis #38; IR does the sun emit?

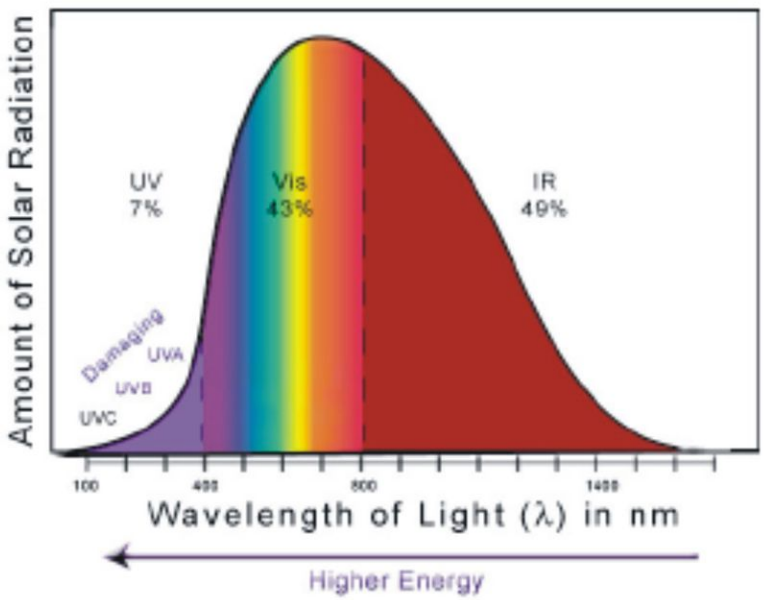


FIGURE 2.6

Does all the radiation from the sun reach the earth?

The Earth's Atmosphere Helps Protect Us

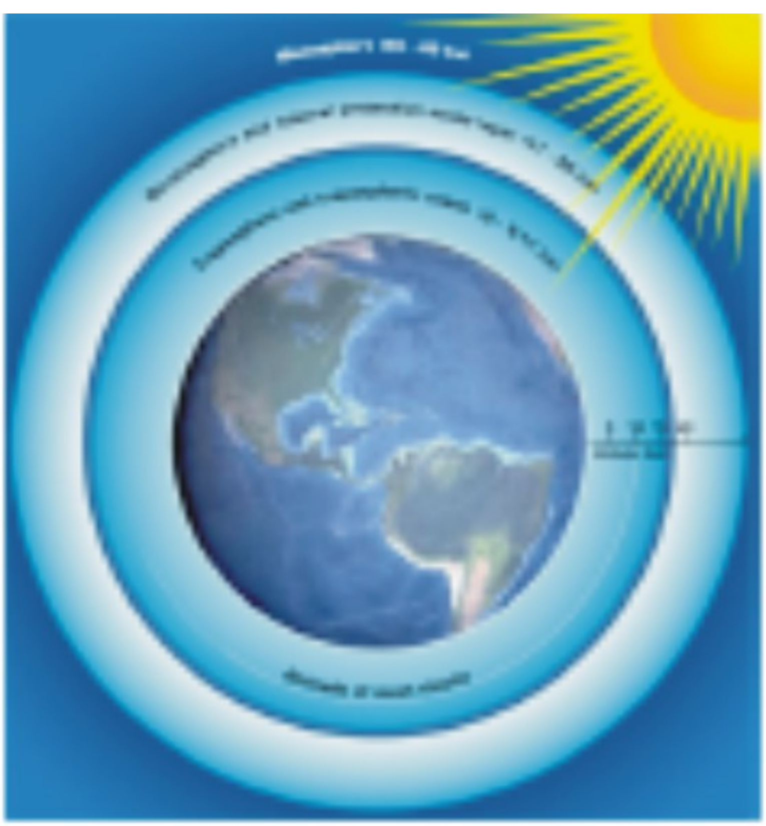


FIGURE 2.7

- Some of the sun's radiation is absorbed by particles in earth's atmosphere
  - Water vapor (H_20) absorbs IR rays
  - Ozone (O_3) absorbs some UV rays
  - Visible rays just pass through
- Challenge Questions

1. What happens if the Ozone layer is partially or completed destroyed?
2. Why are we concerned about UV, but not IR or visible light?

How can the sun's rays harm us?

Sun Rays are Radiation

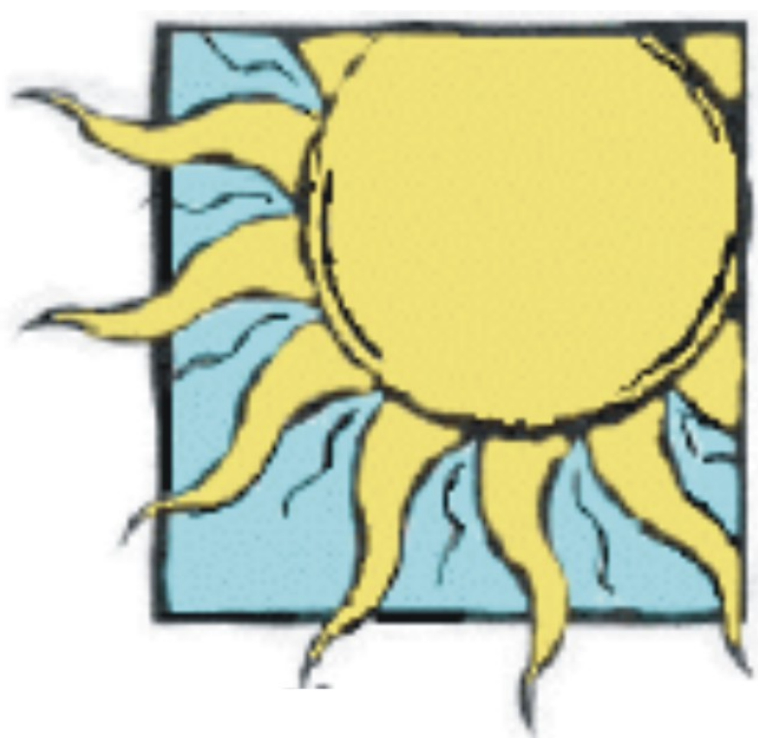


FIGURE 2.8

- Light radiation is often thought of as a wave with a wavelength (λ) and frequency (f) related by this equation:

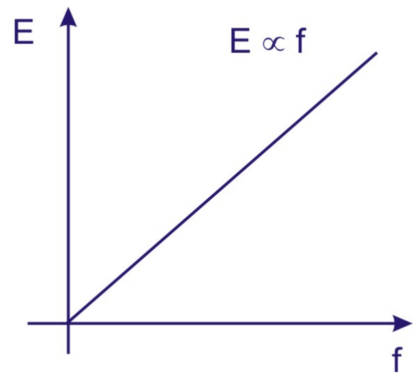
$$C = \lambda \times f$$

- Since c (the speed of light) is constant, the wavelength and frequency are inversely related

$$\lambda = \frac{c}{f} \qquad f = \frac{c}{\lambda}$$

- This means that light with a short wavelength will have a high frequency and visa versa

Radiation Energy I



1. Energy Comes in Packets

- The size of an energy packet (E) is determined by the frequency of the radiation (f)

$$E = h \times f$$

- Radiation with a higher frequency has more energy in each packet
- The amount of energy in a packet determines how it interacts with our skin

Radiation Energy II

2. Total Energy

- This relates not only to how much energy is in each packet but also to the total number of packets arriving at a given location (such as our skin)
- Total Energy depends on many factors including the intensity of sunlight
- The UV Index rates the total intensity of UV light for many locations in the US daily:

http://www.epa.gov/sunwise/uvindex.html

Skin Damage I

- The kind of skin damage is determined by the size of the energy packet $(E = h * f)$
- The UV spectrum is broken into three parts:
  - Very High Energy (UVC)
  - High Energy (UVB)
  - Low Energy (UVA)
- As far as we know, visible and IR radiation don't harm the skin

Skin Damage II

- Very high energy radiation (UVC) is currently absorbed by the ozone layer
- High energy radiation (UVB) does the most immediate damage (sunburns)
- Lower energy radiation (UVA) can penetrate deeper into the skin, leading to long term damage

Sun Radiation Summary I

FIGURE 2.9

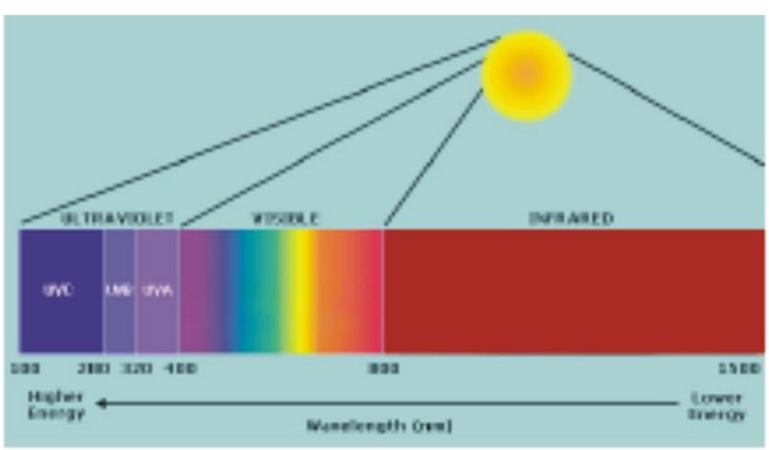


FIGURE 2.10

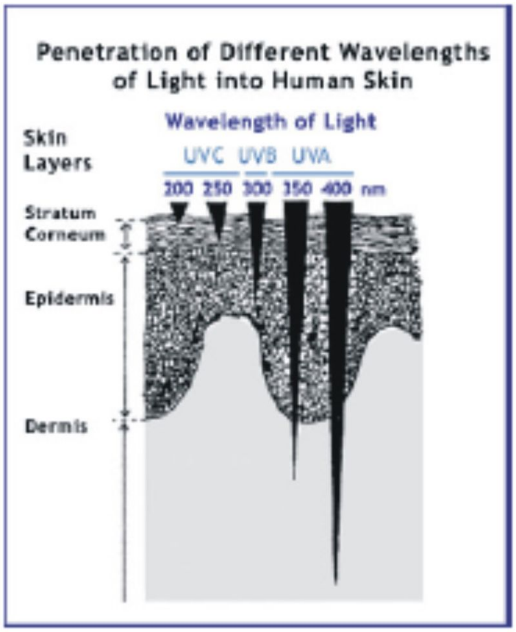


FIGURE 2.11

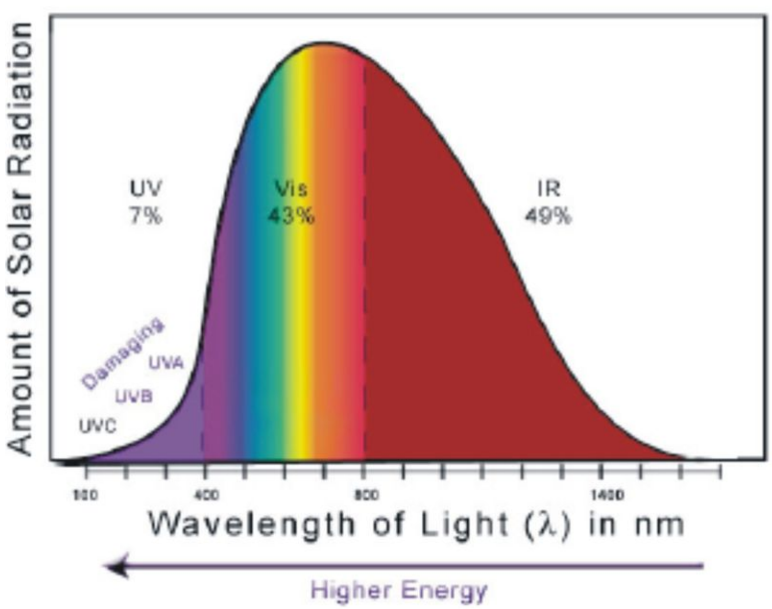


FIGURE 2.12

TABLE 2.14: Sun Radiation Summary II

Radiation Type	Characteristic Wavelength (λ)	Energy per Photon	% of Total Radiation Emitted by Sun	Effects on Human Skin	Visible to Human Eye?
	Increasing Energy	**Increasing Wavelength**			
UVC	$\sim 200-290$ nm (Short-wave UV)	High Energy	$\sim 0\%$ ($< 1\%$ of all UV)	DNA Damage	No
UVB	$\sim 290-320$ nm (Mid-range UV)	Medium Energy	$\sim .35\%$ (5% of all UV)	Sunburn DNA Damage Skin Cancer	No
UVA	$\sim 320-400$ nm (Long-wave UV)	Low Energy	$\sim 6.5\%$ (95% of all UV)	Tanning Skin Aging DNA Damage Skin Cancer	No
Vis	$\sim 400-800$ nm	Lower Energy	$\sim 43\%$	None Currently Known	Yes
IR	$\sim 800-120,000$ nm	Lowest Energy	$\sim 49\%$	Heat Sensation (high λ IR)	No

With all of this possible damage, it pays to wear sunscreen, but which one should you use?

There are So Many Choices?

The Challenge: 3 Essential Questions

1. What are the most important factors to consider in choosing a sunscreen?
2. How do you know if a sunscreen has “nano” ingredients?
3. How do “nano” sunscreen ingredients differ from other ingredients currently used in sunscreens?

Understanding the Danger: Teacher Notes

Overview

This series of interactive slides sets the context for the unit by describing the dangers of UV radiation and our need to protect ourselves against them. The final slide presents the three driving questions for the lessons in the unit.

Slide 1: Title Slide

Questions for Students: Do you wear sunscreen? Why or why not? Are there nanoparticles in your sunscreen? How do you know?

Slide 2: Why Use Sunscreen? (Question Slide)

Have your students brainstorm ideas about why it is important to use sunscreen.

Slide 3: Too Much Sun Exposure is Bad for Your Body

This slide describes the three main dangers of UV radiation:

- Premature skin aging leads to leathery skin, wrinkles and discolorations or “sun spots.” Eyes can also be damaged by UV radiation leading to cataracts (damage to the eyes which causes cloudy vision).
- Sunburns are not only painful but are also a distress response of the skin giving us a signal that damage is being done.

FIGURE 2.13

FIGURE 2.14

- Skin cancer occurs when UV rays damage DNA in skin cells leading to genetic mutations. The mutated cells grow and divide uncontrollably forming a tumor. If caught early, the cancer can be removed; otherwise it can spread to other parts of the body and eventually cause death.

Slide 4: Skin Cancer Rates are Rising Fast

This slide describes the most dangerous consequence of UV radiation – skin cancer.

It is only recently that being tan came into fashion and that people began to spend time in the sun on purpose in order to tan. In addition, clothing today generally reveals more skin than it did in the past.

The use of tanning beds is not safe and a "base tan" only provides protection of about SPF 4.

Discussion Question for Students: Are there any other reasons that skin cancer **rates** might be rising?

Answer: Improvements in detection technology may mean that we identify more cases inflating the slope of the rise.

Slide 5: What Are Sun Rays? How are they doing damage? (Question Slide)

Have your students brainstorm ideas about what sun rays are and how they interact with our body.

Slide 6: The Electromagnetic Spectrum

Note: The illustrations of the waveforms at the extremes of the wavelength/energy spectrum are not to scale. They are simply meant to be a graphical representation of longer and shorter wavelengths.

You may want to discuss some of the properties and uses of the different parts of the electromagnetic spectrum further with your students:

- Gamma rays result from nuclear reactions and have a very high frequency and energy per photon (very short wavelength). Because they have a high energy, the photons can penetrate into cell nuclei causing mutations in the DNA.

- $X-$ rays are produced in collision of high speed electrons and have a high frequency and energy per photon (short wavelength). Because they have a smaller energy than gamma rays, the $x-$ ray photons can pass through human soft tissue (skin and muscles) but not bones.
- Ultra Violet Light is produced by the sun and has a somewhat high frequency and energy per photon (somewhat short wavelength). Different frequencies of UV light (UVA, UVB) are able to penetrate to different depths of human skin.
- Visible Light is produced by the sun (and light bulbs) and has a medium frequency and energy per photon (medium wavelength). Visible light doesn't penetrate our skin, however our eyes have special receptors that detect different intensities (brightnesses) and frequencies (colors) of light (how we see).
- Infrared Light is emitted by hot objects (including our bodies) and have a low frequency and energy per photon (long wavelength). Infrared waves give our bodies the sensation of heat (for example when you stand near a fire or out in the sun on a hot day.)
- Radio Waves are generated by running an alternating current through an antenna and have a very low frequency and energy per photon (very long wavelength). Because they are of such low energy per photon, they can pass through our bodies without interacting with our cells or causing damage.

Slide 7: The Sun's Radiation Spectrum I

Sun rays are a form of electromagnetic radiation. Electromagnetic radiation is waves of oscillating electric and magnetic fields that move energy through space.

Discussion Question for Students: What is the difference between UVA, UVB and UVC light?

Answer: They have different wavelengths, frequencies (UVC: $\sim 100-280$ nm ; UVB: $\sim 280-315$ nm ; UVC $\sim 315-400$ nm) and thus different energies.

Note: The division of the UV spectrum (as well as the division of UV, visible, infrared etc.) is a categorization imposed by scientists to help us think about the different parts of the electromagnetic spectrum, which is actually a continuum varying in wavelength and frequency.

Slide 8: The Sun's Radiation Spectrum II

The sun emits primarily UV, visible and IR radiation. $< 1\%$ of the sun's radiation is $x-$ rays, gamma waves, and radio waves.

The amount of each kind of light emitted by the sun is determined by the kinds of chemical reactions occurring at the sun's surface.

Slide 9: Does all the radiation from the sun reach the earth? (Question Slide)

Have your students think about what might happen to the radiation as it travels through space.

If students bring up the idea of the ozone layer as protecting the earth, ask them to think about *how* it does this. (It does this by absorbing harmful UV rays – in other words capturing their energy so it doesn't reach the earth).

Slide 10: The Earth's Atmosphere Helps Protect Us

The earth's atmosphere is made up of several layers of gases surrounding the planet. The two closest layers are referred to as the troposphere (closest to the earth, where most clouds are found) and the stratosphere (farther from the earth, where the protective ozone layer resides). Beyond this there is (in increasing order of distance from the earth), the mesosphere, thermosphere and exosphere.

You may want to remind your students that absorption is the process by which atoms or molecules capture radiation energy.

Answers to Challenge Questions on Slide:

1. What happens if the Ozone layer is partially or completed destroyed?

As the ozone layer is depleted, more of the UV light emitted by the sun will reach the earth. UV depletion is cause by several chemicals used by humans, particularly the CFCs (chlorofluorocarbons) used in many old-style aerosol sprays. Though international agreements limiting the use of such chemicals has helped the problem, the fight continues. As the Canadian Space Agency reports, in 2000:

"Observations showed a strong depletion of the ozone layer over the Arctic, by as much as 60% in some layers of the atmosphere. In the lower stratosphere, near the South Pole, the hole reached a record size in spring 2000, measuring 28.3 million kilometers. *The affected area extended to the southern tip of South America."*

(*Source:* http://www.space.gc.ca/asc/eng/sciences/ozone_layer.asp)

2. Why are we concerned about UV, but not IR or visible light?

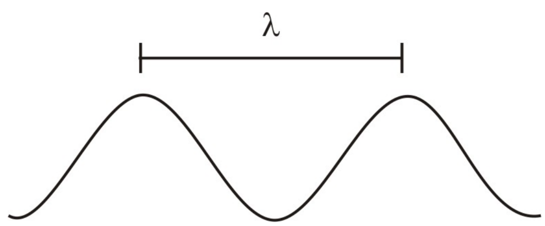
We are concerned about UV radiation because it is higher in energy than IR and visible radiation (this will be covered in more detail in the following slides). Even though there is less of it, it has the potential to damage humans, while it is currently thought that IR and visible radiation do not.

Slide 11: How can the sun's rays harm us? (Question Slide)

Have your students brainstorm ideas about how sun rays might interact with our body. What part(s) of our body do they interact with? How do they affect them?

Slide 12: Sun Rays are Radiation

If students are not already familiar with the concept of wavelength, it may help to draw a wave on the board and indicate that the wavelength is the distance between peaks.



The speed of light in a vacuum is always the same for all wavelengths and frequencies of light. ($c = 300,000,000\ \mathrm{m/s}$)

You may wish to point out to students that the letter ' c ' is the same c in the famous $E = mc^2$ equation showing the relationship between matter and energy.

You may also want to discuss the concept that all light travels at the same speed in the same medium and that this does not depend on the frequency or wavelength of the wave. For example, in other mediums (e.g. air, water) light travels slower than in a vacuum. The speed of all light in water is $\sim 225,563,909\ \mathrm{m/s}$ (only 75% of speed in a vacuum.)

Slide 13: Radiation Energy I

Example: Imagine that you are outside your friend's window trying to get their attention. You can throw small pebbles at the window one after another for an hour and it won't break the window. On the other hand, if you throw a big rock just once, you will break the window. It doesn't matter if all the pebbles put together would be bigger and heavier than the one rock; because their energy is delivered as separate little packets, they don't do as much damage. The same is true with energy packets.

h is Planck's constant (6.26×10^{-34} J s)

Slide 14: Radiation Energy II

Total Energy can not be predicted by the frequency of light.

You may want to talk with your students about the different things that the total energy depends upon. For example: time of day (10 am -2 pm is the most direct and strongest sunlight), time of year, amount of cloud cover (though some UV always gets through), altitude.

You may want to explore the UV index site with your students and look at how the index varies by location.

Slide 15: Skin Damage I

Discussion Question for Students: Which kinds(s) of UV light do you think we are most concerned about and why?

Answer: The theoretical answer would be $UVC > UVB > UVA$ in terms of concern because of energy packet size. This is true for acute (immediate) damage, though as shown in next slide, UVA has now been found to cause damage in the long term. UVC is currently not a major concern because it is absorbed by the atmosphere and thus doesn't reach our skin.

Slide 16: Skin Damage II

Premature aging is caused by damage to the elastic fibers (collagen) in the dermal layer of the skin. Because UVA radiation has a lower frequency and thus lower energy per photon, it is not absorbed by the cells of the top layer of the skin (the epidermis) and can penetrate deeper into the skin (to the dermis) where it does this damage.

Both UVA and UVB can enter the cell nucleus and cause mutations in the DNA leading to skin cancer.

Most of the rapid skin regeneration occurs in the epidermal layer. The dermal layer does not regenerate as quickly and thus is subject to long term damage.

Slide 17: Sun Radiation Summary I

This slide and the following one sum up the differences between the different kinds of radiation emitted by the sun. There is a corresponding student handout that students can use as a quick reminder during the course of the unit.

This graph contains the all the information about wavelength, frequency, energy and amount of each kind of radiation emitted by the sun. Note that the different "kinds" of radiation are really points on a continuum.

Common Misconception: We see "black light" (UVA light) because it is close to the visible spectrum.

The Real Deal: If that were true, we would be able to see all objects as bright under black light and that doesn't happen. For example at a party only certain clothes appear bright. What actually happens is that black light causes some materials to fluoresce or phosphoresce meaning they absorb the UVA light and re-emit violet light in the visible spectrum that our eyes can detect.

Slide 18: Sun Radiation Summary II

This slide and the previous one sum up the differences between the different kinds of radiation emitted by the sun. There is a corresponding student handout that students can use as a quick reminder during the course of the unit.

This chart summarizes the all the information from the previous graph and lists the effects of each kind of radiation on the human body.

Note: Different diagrams may have different cutoffs for the divisions between UVA, UVB, UVC, visible and IR. This is because the electromagnetic spectrum is a continuum and the divisions between categories are imposed by scientists, thus not always well agreed upon.

Example: What determines if it is a "warm" versus a "hot" day? If you set the cutoff at 80 degrees Fahrenheit does that mean that a change from $79°F$ to $81°F$ is more meaningful than a change from $77°F$ to $79°F$?

Slide 19: With all of this possible damage, it pays to wear sunscreen, but which one should you use? (Question Slide)

Discussion Questions for Students: What do you look for when you are buying a sunscreen and why? Do you think that your sunscreen is doing a good job to protect you?

Answers will vary. The goal of the discussion is for students to get their existing knowledge out on the table and to start to think critically about the consumer decisions they make and how they relate to science.

Slide 20: There Are So Many Choices!

This slide is an animation presenting the many different sunscreens available and the many different claims their labels make.

Slide 21: The Challenge: 3 Essential Questions

These three questions will guide the upcoming unit:

1. What are the most important factors to consider in choosing a sunscreen?
2. How do you know if a sunscreen has "nano" ingredients?
3. How do "nano" sunscreen ingredients differ from other ingredients currently used in sunscreens?

Each of the unit activities will help students develop their ideas about the questions. By the end of the unit, students should be able to explain and justify their answers to each question. For now, use the Clear Sunscreen Initial Ideas Worksheet to gives students the chance to brainstorm their initial answers to these questions before they begin the unit.

Clear Sunscreen Initial Ideas: Teacher Instructions

The goal of this exercise is to have your students "expose" their current ideas about sunscreens and human use of nano-products before they engage in learning activities that will explore these questions. You should let your students know that this is not a test of what they know and encourage them to makes guesses which they will be able to evaluate based on what they learn in the unit. You may also want to have your students share their ideas with the class (there are no "bad" ideas at this stage) and create a giant class worksheet of ideas. Students can then discuss whether or not they think each of these statements is true and why.

Write down your initial ideas about each question below and then evaluate how confident you feel that each idea is true. At the end of the unit, we'll revisit this sheet and you'll get a chance to see if and how your ideas have changed.

TABLE 2.15:

1. What are the most important factors to consider in choosing a sunscreen?	**How sure are you that this is true?** Not sure	**How sure are you that this is true?** Kind-of-Sure	**How sure are you that this is true?** Very Sure	**End of Unit Evaluation**
2. How do you know if a sunscreen has "nano" ingredients?	**How sure are you that this is true?** Not sure	**How sure are you that this is true?** Kind-of-Sure	**How sure are you that this is true?** Very Sure	**End of Unit Evaluation**
3. How do "nano" sunscreen ingredients differ from most other ingredients currently used in sunscreens?	**How sure are you that this is true?** Not sure	**How sure are you that this is true?** Kind-of-Sure	**How sure are you that this is true?** Very Sure	**End of Unit Evaluation**

Ultra-Violet (UV) Protection Lab Activity: Teacher Instructions #38; Answer Key

Summary of Materials to Order Ahead of Time

Source: Educational Innovations (www.teachersource.com)

Portable UV light - 1 (#UV-635, $ 10.95 each)

Purple UV beads -1 set (#UV-PUR, $ 6.95 per 250 bead package)

UV Bead Color Guide - 1 set per lab group (#UV-360, $ 2.95 each)

Clear UV blocking glass - 1 set (#FIL-235, $ 9.95 per set of two discs)

Introduction

It is important to protect our skin from damaging UV radiation, but how do we know how well we are protecting ourselves? Is wearing a light shirt at the beach as effective as wearing sunscreen? Is it better protection? Do thicker, whiter sunscreens protect us better than transparent sprays? Can we tell how well something will block UV by looking at its appearance?

Lab Explanation

In this lab students should discover that opacity and UV blocking are not related. Clear substances can be UV blockers and some opaque substances are not very good UV blockers. This is true because UV and visible light have different wavelengths and frequencies, thus they can interact differently with the same substance.

Research Question

In this lab you will be investigating the following research question:

- Does the appearance of a substance (its opacity) relate to its ability to block UV light?

Opacity

The *opacity* of a substance is one way to describe its appearance. Opacity is the opposite of how transparent or "see-through" something is; for a completely opaque substance, you cannot see through it at all. Opacity is a separate property than the color of a substance – for example, you can have something that is yellow and transparent like apple juice or something that is yellow and opaque like cake frosting.

Hands-On Opacity Examples

- Yellow frosting and yellow food coloring in water
- Grape juice (full concentration and several glasses of watered down versions)
- Stained glass (show different pieces of the same color but varying opacity)

Hypothesis

Do you think that UV blocking ability relates to a substance's opacity? Would you expect transparent or opaque substances to be better UV blockers? If you are right, what implications does this have for how you will protect yourself the next time you go to the beach? Write down your best guesses to answer these questions and explain why you think what you think.

Judging Student Hypotheses

Student answers may say that they are, are not, or are partially related. Student answers should not be judged on the correctness of the hypothesis, but can be evaluated on:

- The consistency of the answer (if they do relate than they should predict opaque substances to block better, if they don't relate, neither group of substances should be expected to be better blockers)
- Their justification for their answer (are they basing it on personal experience, scientific knowledge, etc.)

Materials

- Assorted white substances varying in opacity (for example: different sunblocks, sunscreens, sungels, glass pieces, white t-shirts of varying thicknesses, white tissue paper, white paper of varying thicknesses, laundry detergent, white paint, white face makeup)
- Eight paper cups
- One micro spoon
- Sunscreen Smear Sheet (Xerox form at the end of the lab onto acetate transparencies)
- Black construction paper (For judging opacity of white substances)
- UV light source (Available from Educational Innovations, Inc., #UV-635, direct sunlight on a bright day will also work)
- UV sensitive bead testers (Made from the following, instructions below)
  - UV sensitive beads (Available from Educational Innovations, Inc., #UV-PUR)
  - Large wooden craft sticks
  - Super glue
- UV bead color guide (Available from Educational Innovations, Inc., #UV-360)
- Cotton swabs (for apply sunscreen to the Sunscreen Smear Sheet)
- Alcohol wipes (for cleaning sunscreen off the Sunscreen Smear Sheet)

Making UV Beads into "Bead Testers"

To make the beads into bead testers you will need to melt them and glue them to wooden craft sticks. This makes them much easier for handling and applying sunscreen:

Here are the directions for melting and mounting the beads as discs.

1. Preheat oven or toaster oven to $300°F$.
2. Cover a cookie sheet with aluminum foil.
3. Arrange beads on the cookie sheet. Place them one inch from each other and make sure they are laying flat on the sheet.
4. Place beads in oven and set timer for 15 minutes .
5. When 15 minutes is over, the beads should have melted and now look like clear discs.
6. Remove from oven to cool. They will harden to white discs within five minutes.
7. Using super glue, attach one disc to a large wooden craft stick. Each student group should have three disc sticks, one labeled "C1" for Control 1, one labeled "C2" for Control 2, and the third labeled "E" for Experimental.

Alternative Option: Super glue two discs directly onto the UV bead color guide tube. If you choose to do this, mount the beads while they are slightly malleable and not cooled completely—approximately $1-2$ minutes after removing melted beads from the oven.

Choosing Substances for Students to Test

You will want to have a selection of substances that range in both blocking ability and appearance (from clear to opaque). Here are some suggestions of substances to use:

- "Old" zinc-oxide sunblock that goes on white (As a substitute, Desitin is a cream sold for diaper rash that contains 40% zinc oxide.)
- "New" nano zinc-oxide sunblock that goes on clear
- A variety of regular sunscreens
- Clear sunscreen gels or sprays
- Clear UV blocking glass or plastic (A set of two clear plastic discs, one UV blocking, one not is available from Education Innovations, Inc., #FIL-235, $ 9.95 per set of two discs)

- White t-shirts of varying thickness
- Liquid laundry detergent (the ones with whitener will block some UV light)
- Old white t-shirts (if the old ones have been washed many times with whitening detergent they will block some UV light)
- White paper of vary thickness (tissue paper, printer paper, construction paper)
- White paint or white face make-up

Important Notes on Using Sunscreens

- Make sure to tell students not to put the sunscreen on their bodies in case of an allergic reaction
- To avoid mess, you may want to have sunscreens available to students in a bowl or large cup

Procedure

Part I: Choose Your Samples

Goal: Choose a group of substances from the ones provided by your teacher that you think will best help you determine if opacity is related to UV blocking.

- Obtain eight small paper cups. Obtain a small sample of each of the substances you have chosen. Label each cup with the name of the substance.

  Tip: Try to choose substances that vary in their opacity and that you would expect to vary in their blocking ability.

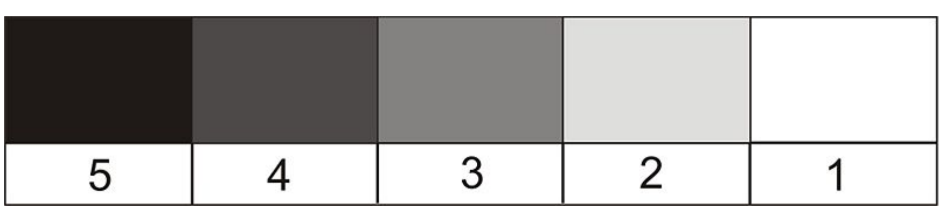
Part II: Judge the Opacity

Goal: To make observations about the appearance (opacity) of the substances you chose, using your eyes as the instruments.

- Obtain a Sunscreen Smear Sheet. Place it on top of a black sheet of paper.
- Label one square with the name of each substance you are going to test.
- Use the micro spoon to measure out the first substance (make sure to use an equal amount of all the other substances).
- Then use the cotton swab to smear the substance onto the Sunscreen Smear Sheet, evenly covering a whole square with a thin layer. (For solid substances, just place them on top of the sheet).
- How well can you see through the substance to the black sheet of paper?
- Use the Opacity Guide on the next page to rank each sample on a 1 to 5 scale.

  Use 5 to represent no opacity (you cannot see the substance at all). Use 1 to represent complete opacity (you can't see any black through the sample).

- Record your observations into the Data Chart in this packet.
- Repeat for each of your substances.



Part III: Test the UV Blocking

Goal: Use UV-sensitive beads to determine how effective your chosen substances are in blocking UV-light.

Student Question: Why don't we judge UV blocking ability with our eyes?

Answer: Because our eyes can't detect UV light, we need to use something that can

- Obtain 3 UV bead testers:
  - Bead Tester "C1" for Control 1. This bead will always be kept out of the UV light and will show you the lightest color that the bead can be. Keep this in the envelope until you need it.
  - Bead Tester "C2" for Control 2. This bead will always be exposed to the UV light and should always change color to let you know that the UV light is reaching the bead. This bead will show you the darkest color that the bead can reach.
  - Bead Tester "E" for Experimental. Keep this in its envelope so that it is not exposed to any UV light while you are not using it.

Checking Bead Tester C1 and C2

- Use UV bead color guide to record the initial bead color number $(2-10)$ of C1 on your data chart.
- Expose C2 to the UV light for 30 sec . and quickly compare it to the UV bead color guide. Record the bead color number $(2-10)$ on your data chart.

Using Bead Tester E with Your Substances

- To test the UV blocking of a substance, hold Bead Tester E under the square for that substance on the Sunscreen Smear Sheet. (For solid substances, just hold Bead Tester E directly behind them).
- Expose Bead Tester E (covered by the substance) and Bead Tester C2 uncovered) to your UV lamp (or direct sunlight) for 30 secs .
- Take both Bead Testers out of the light, uncover Bead Tester E, and observe any changes to the color of the beads using the UV bead color guide. Record the bead color number $(2-10)$ for both E and C2 on your data chart.

Tip

For solid substances, student may confuse the shadow cast by the object with the color change of the bead. The best way to accurately judge the color change of a bead with a shadow on it is by placing the color guide in the shadow as well.

- Repeat for each of your substances.

Data Chart

Initial C1 Bead Color Number________

Initial C2 Bead Color Number_________

TABLE 2.16:

Substance Name (Include SPF if applicable)	Appearance (Describe)	Opacity (1 to 5 rating)	Color of UV bead "E" (2 to 10 rating)	Color of UV bead "C2" (2 to 10 rating)	Observations and Notes

Analysis

Tip

Students may have difficulties understanding that "no pattern" can be an important and informative finding. After giving students a chance to work on the analysis section in their groups, you may want to have them come together as a class to discuss their results and focus specifically on what it means to not have a pattern and how you know whether you have "no pattern" or "not enough data." If there is time, you may want to combine student data into one giant chart and discuss the results with students.

Now you need to analyze your data to see if it helps to answer the research question:

Does the appearance of a substance (opacity) relate to its ability to block UV light? One of the ways that scientists organize data to help them see patterns is by creating a visual representation. Below you will see a chart that you can use to help you analyze your data.

To fill in the chart, do the following for each substance that you tested:

1. Find the row that corresponds to its opacity.
2. Find the column that corresponds to its UV blocking ability.
3. Draw a large dot • in the box where this row and column intersect.
4. Label the dot with the name or initials of the substance.

After you have filled in the chart, answer the analysis questions that follow.

TABLE 2.17:

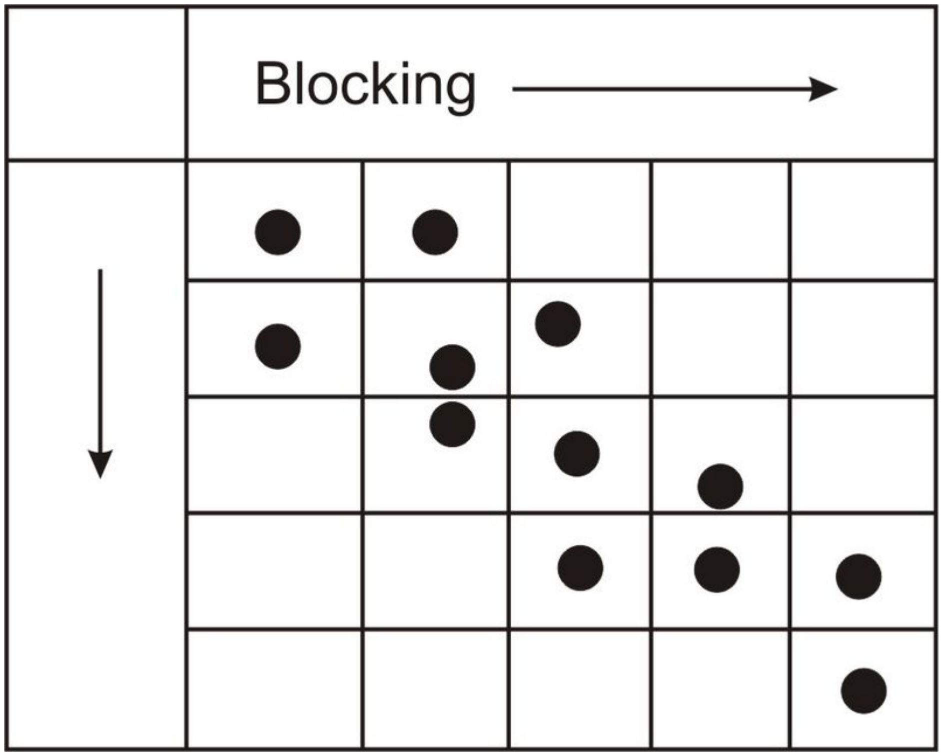
UV Blocking Ability → Opacity ↓	No Blocking (10)	Low Blocking (8)	Medium Blocking (6)	High Blocking (4)	Total Blocking (2)
5 Fully Transparent					
4					
3					
2					
1 Fully Opaque					

1. Look at the visual representation of your data that you have created and describe it. Note any patterns that you see. Remember that seeing no pattern can also give you important information.

Answer

Ideally the dots will be scattered randomly throughout the graph and not show any pattern. Individual data sets may show some concentration of dots in a particular part of the chart due to the substances tested, but there should not be a "line" of dots in any direction that would indicate a correlation between opacity and UV blocking ability. You may want to discuss with students the difference between a pattern (most dots are in the lower left corner) and a relationship (dots form a line showing how one variable varies with the other.)

2. What pattern would you expect to see if there is a relationship between the appearance of a substance (opacity) and its ability to block UV light? Draw the pattern by coloring in the grid below.



Tip

Students might say the opposite (a diagonal line running from the bottom left to the top right indicating that more transparent substance block better) which is possible (though counter-intuitive). If they say this, ask them to justify why they think this would be.

3. Does your chart match the pattern you would expect to see if there is a relationship between opacity and UV blocking ability?

□ Yes

■ No

■ I'm not sure

Tip

Either the 2^{nd} or the 3^{rd} answer can be correct; students should not have data that supports a relationship between the variables.

4. What does this answer mean in practical terms? What does it tell you about well you can judge the effectiveness of sun protection by looking at its appearance? How might this affect your sun protection activities?

Answer

The answer of "no pattern" means that you cannot tell how well something will protect you from the sun by looking at its appearance. For example, clear sunglasses can provide UV protection to your eyes and a white tee-shirt may not fully protect the skin underneath. This means that it is very important to pay attention to SPF (and other) ratings of sun protection and not make assumptions based on appearance.

5. Do you think that increasing the number of substances you tested would change your answer? Why or why not?

Answer

No, adding substances will help clarify the answer in situations where the data is not clear, but it should not change an answer strongly supported by the data.

6. How confident are you that the answer you came up with is correct? Do you think that increasing the number of

substances you tested would change *how sure you are* of your answer? Why or why not?

Answer

Students should discuss their confidence in relation to their data. For example the amount of data points they have, the range of substances they tested (and that were available to them).

More data points would make the existence (or lack of a pattern) more clear. It also increases confidence that the data points found were not "flukes" but representative of the overall pool of possible substances to test.

Conclusions

1. Answer the research question:

□ Yes, there is a relationship.

■ No, there is not a relationship.

■ I'm not sure if there is a relationship.

Tip

Either the 2^{nd} or the 3^{rd} answer can be correct; students should not have data that supports a relationship between the variables.

2. This is how the evidence from the experiment supports my answer: (Make sure to be specific and discuss any patterns you do or do not see in the data.)

Answer

Students should discuss how their data compares to what data for a pattern would look like.

3. Identify any extra variables that may have affected your experiment:

Answer

Possible answers include the amount (thickness) of sunscreen applied and incomplete cleaning of sunscreen from previous trial.

If you are using natural sunlight, the amount of UV light shining on the beads may also vary between trials. If this is the case, students should notice differences in the bead color number for C2 between trials.

4. How could you control for these variables in future experiments?

Answer

Possible answers include measuring sunscreen for application and the use of disposable tester sticks.

5. What changes would you make to this experiment so that you could answer the research question better?

Answer

Possible answers include using more substances (students should give examples) and using better measurement tools (for example beads with a permanent color change, a digital color reader etc.).

6. All experiments raise new questions. Sometime these come directly from the experiment and others are related ideas that you become curious about. What is a new research question that you would want to investigate after completing this experiment?

Answer

Possible answers include the relationship between color (hue) and blocking ability, the relationship between blocking claims (advertising) and blocking ability and the relationship between amount applied (of sunscreen) and blocking ability.

TABLE 2.18: Sunscreen Smear Sheet

Sample:	Sample:	Sample:	Sample:

TABLE 2.19:

Sample:	Sample:	Sample:	Sample:

TABLE 2.20: Sunscreen Smear Sheet

Sample:	Sample:	Sample:	Sample:

TABLE 2.21:

Sample:	Sample:	Sample:	Sample:

All About Sunscreens

Teacher Lesson Plan

Contents

- All About Sunscreens: Teacher Lesson Plan
- Sunscreen Ingredients Activity: Teacher Instructions #38; Answer Key
- All About Sunscreens: PowerPoint Slides and Teacher Notes
- Light Reflection by Three Sunscreens: Teacher Answer Key
- Reflecting on the Guiding Questions: Teacher Instructions #38; Answer Key

Orientation

This lesson introduces students to the difference between organic and inorganic sunscreen ingredients and the difference between traditional inorganic ingredients and their nanoversions. These differences include their chemical and bonding structure as well as their effectiveness in blocking UV light from reaching the skin and their appearance.

- The All About Sunscreens PowerPoint takes students through the history of why sunscreens were first developed, their current rating system for UVB blocking ability (SPF) and the need to also consider UVA blocking ability. The slides then explore the different structure and blocking mechanisms of organic and inorganic sunscreen ingredients. Finally the slides discuss what gives inorganic sunscreens their "white" or clear appearance and how the nano versions remedy this situation. There is an optional demonstration of absorption of UV light by chemicals in printed money (as an anti-counterfeiting measure) embedded in the PowerPoint presentation that you can do with your class.
- The Sunscreen Ingredients Activity gives students the opportunity to become familiar with the different ingredients used in sunscreens firsthand. This experience along with the Summary of FDA Approved Sunscreen Ingredients Handout is aimed at making students think to look at the ingredients on the label the next time they go shopping for a sunscreen.
- The Reflecting on the Guiding Questions Worksheet asks students to connect their learning from the activities in the lesson to the overall driving questions of the unit.

Essential Questions (EQ)

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

1. What are the most important factors to consider in choosing a sunscreen?
2. How do you know if a sunscreen has “nano” ingredients?
3. How do “nano” sunscreen ingredients differ from most other ingredients currently used in sunscreens?

Enduring Understandings (EU)

Students will understand:

(*Numbers correspond to learning goals overview document*)

2. Why particle size can affect the optical properties of a material.

3. That there may be health issues for nanosized particles that are undetermined at this time.

4. That it is possible to engineer useful materials with an incomplete understanding of their properties.

5. There are often multiple valid theoretical explanations for experimental data; to find out which one works best, additional experiments are required.

6. How to apply their scientific knowledge to be an informed consumer of chemical products.

Key Knowledge and Skills (KKS)

Students will be able to:

(*Numbers correspond to learning goals overview document*)

1. Describe the mechanisms of absorption and scattering by which light interacts with matter.
2. Describe how particle size, concentration and thickness of application affect how particles in a suspension scatter light.
3. Explain how the phenomenon of seeing things in the world is a human visual response depending on how light interacts with objects.
4. Evaluate the relative advantages (strong blockers, UVA protection) and disadvantages (possible carcinogenic effects, not fully researched) of using nanoparticulate sunscreens.

TABLE 2.22: All About Sunscreens Timeline

Day	Activity	Time	Materials
Day 1 (50 min)	Show All About Sunscreen PowerPoint Slides, using the embedded question slides and teacher's notes to start class discussion. (Embedded graph interpretation activity with student handout) Perform Demonstration associated with PowerPoint Presentation (optional)	50 min	All About Sunscreen PowerPoint Slides & Teacher Notes Computer and projector Optional Demonstration Materials: UV light, different kinds of paper currency. Copies of Light Reflection by Three Sunscreens: Student Handout Light Reflection by Three Sunscreens: Teacher Answer Key
	Homework: Read Sunscreen Ingredients Activity: Student Instructions & Worksheet	20 min	Copies of Sunscreen Ingredients Activity: Student Instructions & Worksheet

TABLE 2.22: (continued)

Day	Activity	Time	Materials
Day 2 (35 min)	Have students work in pairs to complete the data collection and fill in the chart in the Sunscreen Ingredients Activity: Student Instructions & Worksheet. Then have them continue to work in pairs to answer the discussion questions in the worksheet.	10 min	Different kinds of empty sunscreen bottles as listed in the Sunscreen Ingredients Activity: Teacher Instructions & Answer Key
	Bring the class together as a whole to discuss questions 6-8. At the conclusion of the activity hand out and discuss the summary of FDA approved sunscreens.	10 min	Summary of FDA Approved Sunscreen Ingredients: Student Handout
	Have students work individually or in small groups to fill out the Reflecting on the Guiding Questions: Student Worksheet.	5 min	Copies of Reflecting on the Guiding Questions: Student Worksheet
	Bring the class together to have students share their reflections with the class. This is also a good opportunity for you to address any misconceptions or incorrect assumptions from students that you have identified in the unit up till now.	10 min	Reflecting on the Guiding Questions: Teacher Instructions & Answer Key

Name ______________________

Date ______________________

Period ______________

Sunscreen Ingredients Activity: Teacher Instructions #38; Answer Key

This activity allows students to become familiar with the different ingredients used in sunscreens after learning about how different sunscreen ingredients work. After this activity you may want to give students the handout "Summary of FDA Approved Sunscreen Ingredients" to keep as a reference during the unit and the next time they go shopping for a sunscreen.

Most of us (hopefully) apply sunscreen to protect us from the sun when we are going to be outside for a long time.

But how many of us have ever stopped to read the bottle to see what we are putting on our bodies? What kinds of chemicals are used to block the sun rays? Do different sunscreens use different ingredients to block the sun? How might the different ingredients used affect us? In this activity you'll take a look at several sunscreens to see what we are putting on our bodies when we use these products.

Materials

- Five different bottles of sunscreen.

To get a diverse group of sunscreens try to use more than one brand. Also see if you can find the following:

- One sunscreen with a high SPF $(30-50)$.
- One sunscreen with a low SPF $(5-15)$.
- One sunscreen designed for skiers or surfers.
- One sunscreen for sensitive skin or babies.
- One sunscreen that has zinc oxide (ZnO) or titanium dioxide (TiO_2) as an ingredient. *Note: the proper scientific name for TiO_2 is "titanium (IV) oxide", but the older name "titanium dioxide" is more commonly used.*

This activity can be done as homework with a follow up class discussion or as an in-class activity.

As Homework

- Ask your students to visit a local pharmacy or supermarket and do the assignment by looking at the sunscreens they find there. (There is no need for your students to buy any sunscreen.)
- You can ask also each student to research two or three sunscreens and then get together in groups in class to share their results and discuss the questions.
- Before assigning this as homework think about how easy / difficult it will be for your students to get to a pharmacy / supermarket and make sure to allow them enough time to do the assignment.

In-Class

- You will need to either develop your own library of sunscreen products or ask students to bring in products they have lying around at home.
- It is best to use empty sunscreen bottles since the contents of the bottle are not needed for the activity and students may have unknown allergies to some sunscreen ingredients. You can then store the bottles for future use.
- You will want to have a large enough collection and variety of sunscreens so that students aren't waiting to look at the bottles and that they have some choice in what sunscreens to look at.
- It works best to place the sunscreens in stations and have students rotate through them in groups of 2 or 3 .

Instructions

Look at the back of one of the bottles. You should see a list of the "active ingredients" in the sunscreen. These are the ingredients that prevent sunlight from reaching your skin ("inactive ingredients" are added to influence the appearance, scent, texture and chemical stability of the sunscreen.) Also look to see what kind of protection the sunscreen claims to provide. Does it provide UVB protection? UVA protection? Does it claim to have "broad spectrum" protection? What is its SPF number? Does it make any other claims about its protection? Record your observations for each sunscreen in the data chart and then answer the questions that follow.

TABLE 2.23: Data Chart

	Brand	Active Ingredients	SPF	UVB?	UVA?	Broad Spectrum	Price
# **1**							
# **2**							
# **3**							
# **4**							
# **5**							

Questions

Questions 1 – 5 ask students to review and synthesize the information they recorded from the different sunscreens, students should be able to answer these questions on their own based on the data they recorded.

Questions 6 – 8 are deep thought questions that go beyond the information collected in this activity.

1. How many different active ingredients did most of the sunscreens have?

Most sunscreens will have more than one ingredient.

2. What were the most common active sunscreen ingredients you saw? Are these organic or inorganic ingredients?

Common sunscreen ingredients include:

Homosalate, Octinoxate, Octisalate, Oxybenzone, Octocrylene (All organic) Zinc Oxide and Titanium Dioxide (Inorganic) are also common sunscreen ingredients.

(also see FDA Approved Sunscreen Ingredient Resource for full list of ingredients)

3. Did any of the sunscreens you looked at have active ingredients that were very different from the rest? If so, what were they?

Avobezone (Parasol 1789) is sometimes added as because of it UVA blocking abilities. PABA (para aminobenozic acid) is infrequently used because it can irritate skin and stain clothes.

Zinc Oxide and Titanium Dioxide is sometimes found in sunscreens designed for sensitive skin, babies and high SPF ski / surf sunscreens.

4. Were you able to find a sunscreen with inorganic ingredients in it? If so, which one(s) contained them?

Zinc Oxide and Titanium Dioxide (the only 2 FDA approved inorganic ingredients) are often found in sunscreens designed for sensitive skin, babies and high SPF ski / surf sunscreens.

5. How many of your sunscreens claimed to have UVA protection? UVB protection? Broadband protection?

Most all sunscreens claim both UVB #38; UVA protection, but since SPF only measures UVB protection, UVA protection claims currently do not need to be substantiated.

Broadband protection is a general claim of protection for a wide spread of different wavelength of the electromagnetic spectrum bands. It is usually meant to imply that the sunscreen protects from both UVB $(280-320\text{ nm})$ and UVA $(320-400\text{ nm})$ radiation, however UVA protection is not yet regulated (see above), so this claim does not have to be substantiated.

6. Why do you think that many sunscreens have more than one active ingredient? Why can't they just put in more of the "best" one?

Different sunscreen ingredients prevent different wavelengths of light from reaching the skin. They block different parts of the UV spectrum.

(A secondary reason is that high concentrations of chemicals on the skin can cause irritation, this is why when the FDA approves a sunscreen ingredient, it also lists the maximum concentration that can be used).

7. You have just looked at a sample of the different chemicals you are putting on your skin when you use sunscreen. Does this raise any health concerns for you? If so, what are some of the things you might be concerned about and why?

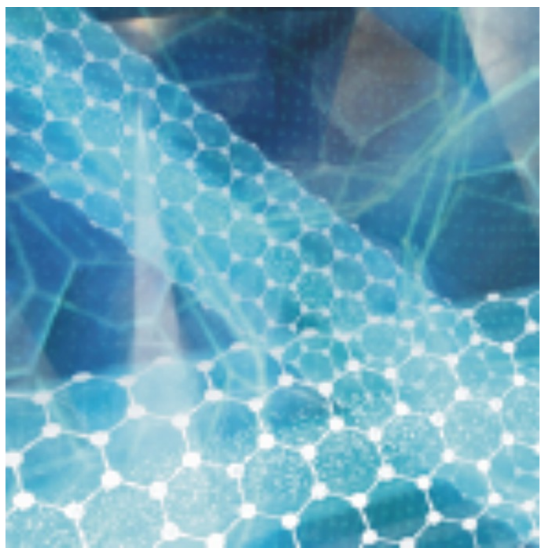
Irritation / allergies, chemicals getting absorbed by the body and having negative effects on the cells, possibility of getting in eyes, mouth or cuts where there is no skin barrier protection, photoactive chemicals can react with the sun to create free radicals which are known to help cause cancer.

8. Where could you go to find out more information about possible health concerns?

The FDA (Food and Drug Administration http://www.fda.gov/) regulates sunscreen ingredients in the U.S. and provides articles related to their use and safety. There are also many consumer watchgroups who provide information both online and in print. Most sunscreen companies do not publish information about health concerns associated with sunscreen. As with all research, it is important to always evaluate the credibility and potential bias of the author or organization presenting the information.

You may want to give your students an assignment to search online for information about current health concerns related to nanoparticle use in sunscreens.

All About Sunscreens



What do Sunscreens Do?

- Sunscreens are designed to protect us by preventing UV rays from reaching our skin
- But what does it mean to [U+0080][U+009C]block[U+0080][U+009D] UV rays?

Light Blocking

- Anytime light interacts with some material, 3 things can happen. The light can be transmitted, it can be reflected, or it can be absorbed
- If we say that light is "blocked" it means that it is either absorbed or reflected by the material

If we know that sunscreens block UV light from reaching our skin does that tell us whether they absorb or reflect the light?

Sometimes More Experiments Are Needed

FIGURE 2.15

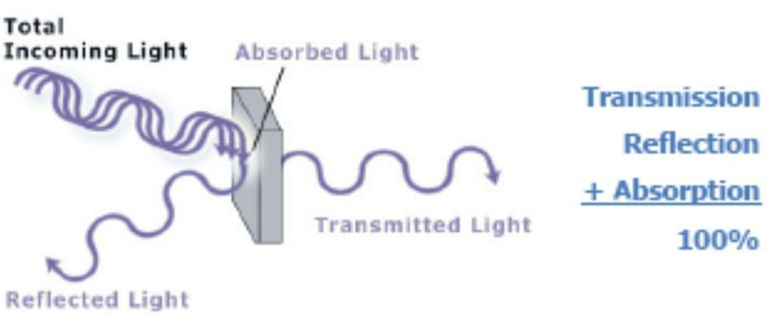


FIGURE 2.16

FIGURE 2.17

- Both absorption and reflection could explain how sunscreens keep UV light from reaching out skin
  - To figure out which mechanism is being used, we ran an experiment where we shine UV light on sunscreens and see if we can detect any reflection

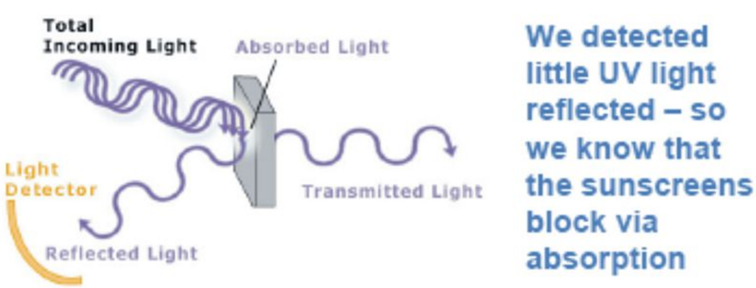


FIGURE 2.18

A Brief History of Sunscreens: The Beginning

- First developed for soldiers in WWII (1940s) to absorb "sunburn causing rays"

A Brief History of Sunscreens: The SPF Rating

- Sunscreens first developed to prevent sunburn
  - Ingredients were good UVB absorbers

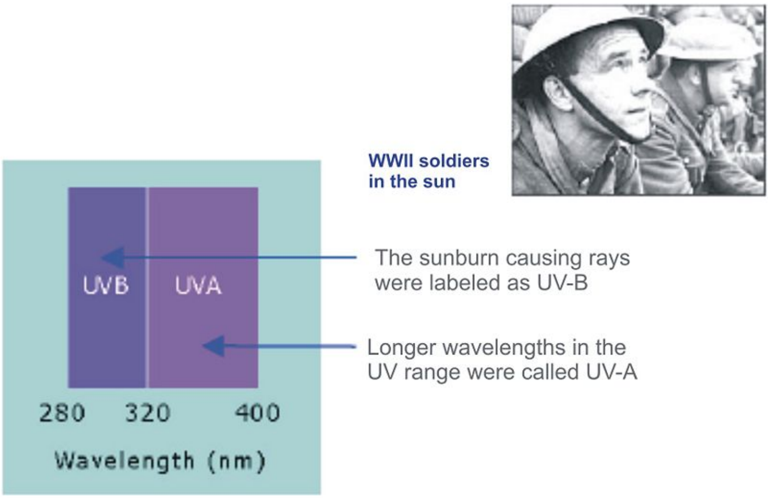
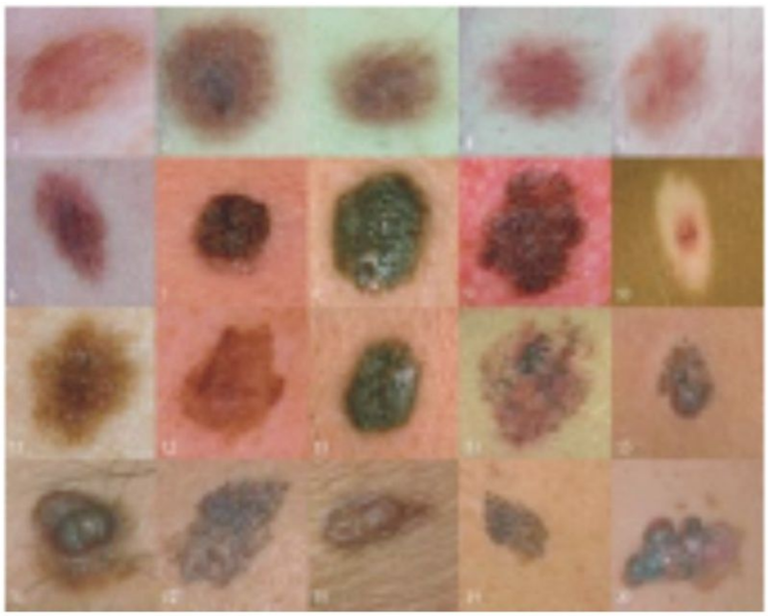


FIGURE 2.19

FIGURE 2.20

- SPF Number (Sunburn Protection Factor)
  - Measures the strength of UVB protection only
  - Higher SPF # = more protection from UVB
  - Doesn't tell you anything about protection from UVA

A Brief History of Sunscreens: The UVA Problem



Twenty different skin cancer lesions

FIGURE 2.21

- UVA rays have no immediate visible effects but cause serious long term damage
  - Cancer
  - Skin aging
- Sunscreen makers working to find UVA absorbers
- *NEW:* The FDA has just proposed a 4− star UVA rating to be included on sunscreen labels!

Low ⋆⋆⋆⋆ Med ⋆⋆⋆⋆ High ⋆⋆⋆⋆ Highest ⋆⋆⋆⋆

How do you know if your sunscreen is a good UVA blocker?

Know Your Sunscreen: Look at the Ingredients

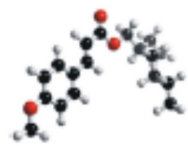
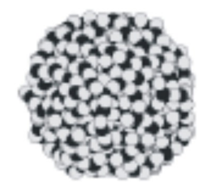
- UV absorbing agents suspended in a lotion
  - "Colloidal suspension"
- Lotion has "inactive ingredients"
  - Don't interact w/ UV light
- UV absorbing agents are "active ingredients"
  - Usually have more than one kind present

FIGURE 2.22

FIGURE 2.23

- Two kinds of active ingredients
    - Organic ingredients and inorganic ingredients

TABLE 2.24: Sunscreen Ingredients Overview

	Organic Ingredients	Inorganic Ingredients
Atoms Involved	Carbon, Hydrogen, Oxygen, Nitrogen	Zinc, Titanium, Oxygen
Structure (not drawn to scale)	Individual molecule 	Clusters of various size 
UV Blocking	Absorb specific bands of UV light	Absorb all UV with $\lambda <$ critical value
Appearance	Clear	Large clusters = White Small clusters = Clear

Organic Ingredients: The Basics

- Organic = Carbon Compounds
    - H, O #38; N atoms often involved
- Structure
    - Covalent bonds
    - Exist as individual molecules
- Size
    - Molecular formula determines size (states the number and type of atoms in the molecule)
    - Typically a molecule measures a few to several dozen Å ($<$ 10 nm)

Organic Ingredients: UV Blocking

Organic Sunscreen Ingredients can absorb UV rays

1. Molecules capture energy from the sun's UV rays
2. The energy give the molecule thermal motion (vibrations and rotations)
3. The energy is re-emitted as harmless long wave IR

Organic Ingredients: Absorption Range

- Organic molecules only absorb UV rays whose energy matches the difference between the molecule's energy levels
    - Different kinds of molecules have different peaks and ranges of absorption
    - Using more than one kind of ingredient (molecule) gives broader protection

Organic Ingredients: Absorbing UVA / UVB

- Most organic ingredients that are currently used were selected because they absorb UVB rays

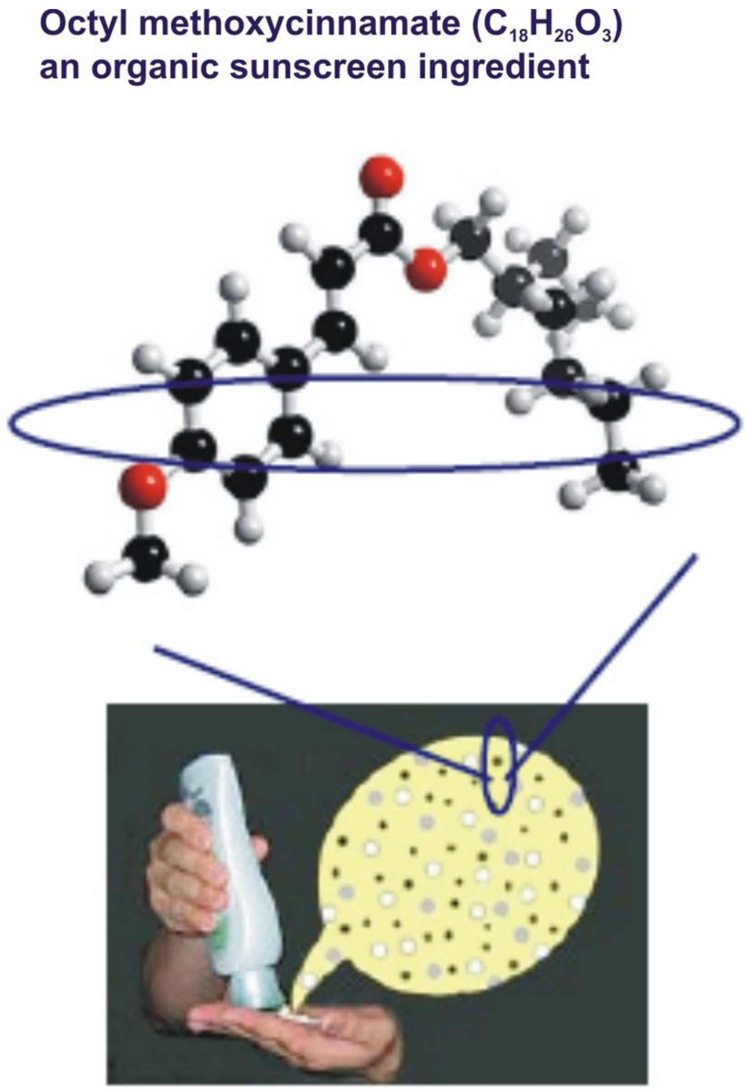


FIGURE 2.24

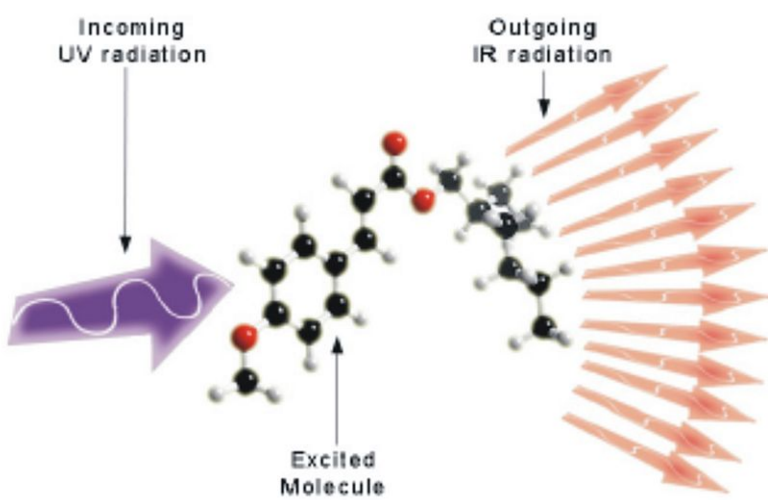


FIGURE 2.25

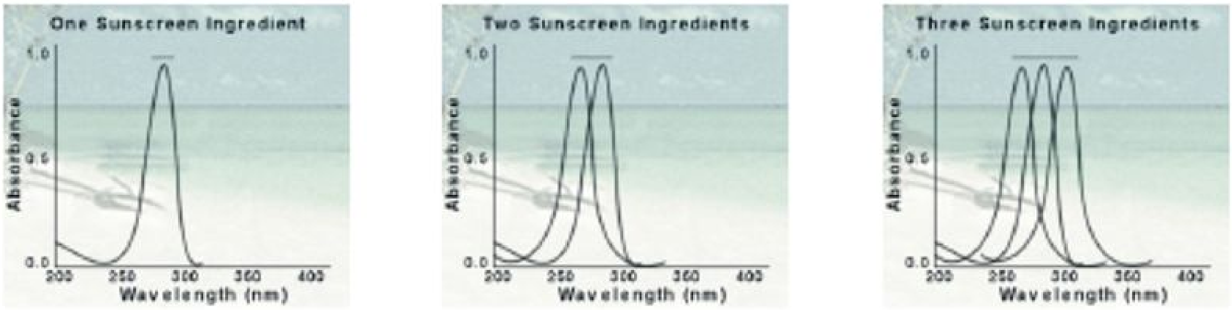


FIGURE 2.26

- The FDA has approved 15 organic ingredients
- 13 of these primarily block UVB rays

- Sunscreen makers are working to develop organic ingredients that absorb UVA rays
  - Avobenzone (also known as Parasol 1789) is a good FDA approved UVA absorber

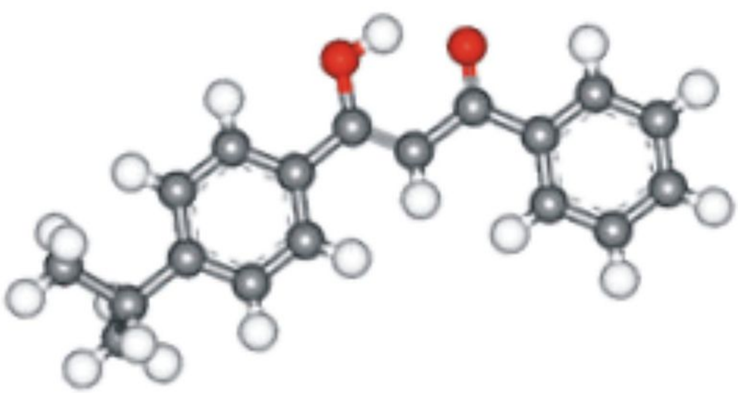


FIGURE 2.27

——Breaking News——

- Ecamsule (Mexoryl SX) is a new sunscreen ingredient designed to absorb UVA rays
  - It is the first new sunscreen ingredient approved by the FDA since 1988

How are inorganic sunscreen ingredients different from organic ones?

How might this affect the way they absorb UV light?

Inorganic Ingredients: The Basics

- Atoms Involved
  - Zinc or Titanium
  - Oxygen
- Structure

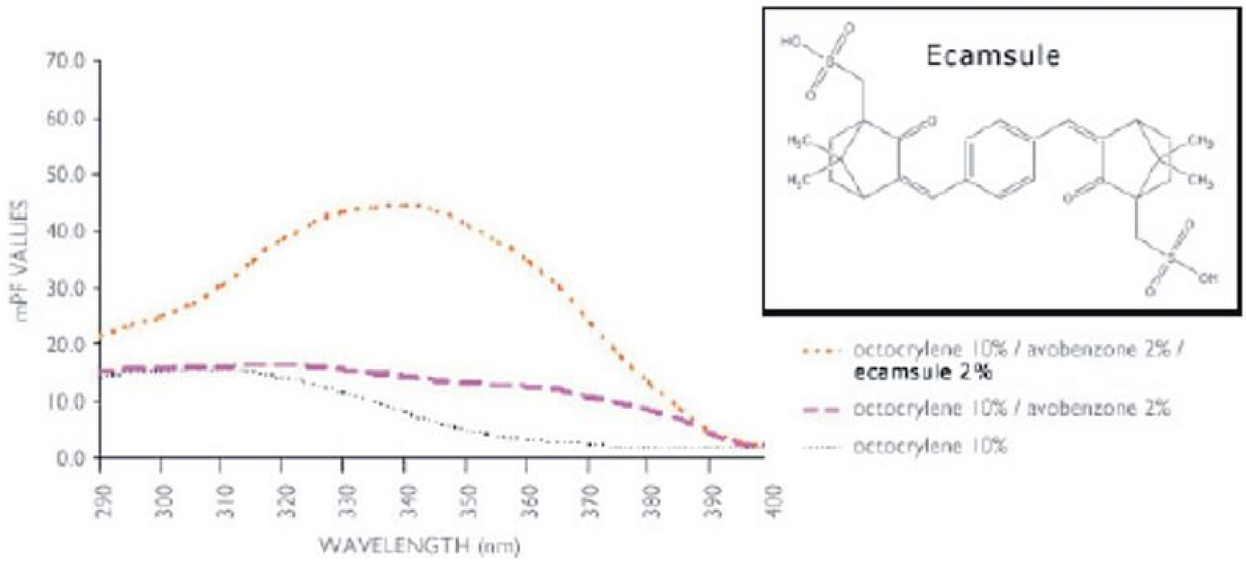


FIGURE 2.28

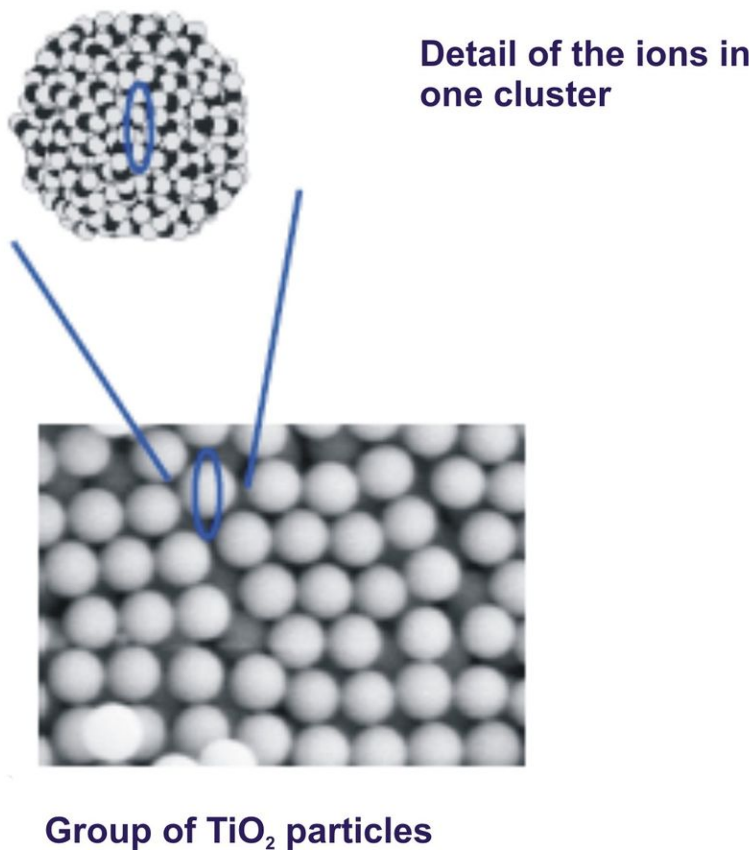


FIGURE 2.29

- Ionic attraction
- Cluster of ions
- Formula unit doesn't dictate size

• Size

- Varies with # of ions in cluster
- Typically ∼ 10 nm – 300 nm

Inorganic Ingredients: Cluster Size

Inorganic ingredients come in different cluster sizes (sometimes called "particles")

• Different number of ions can cluster together
• Must be a multiple of the formula unit

- ZnO always has equal numbers of Zn and O atoms
- TiO_2 always has twice as many O as Ti atoms

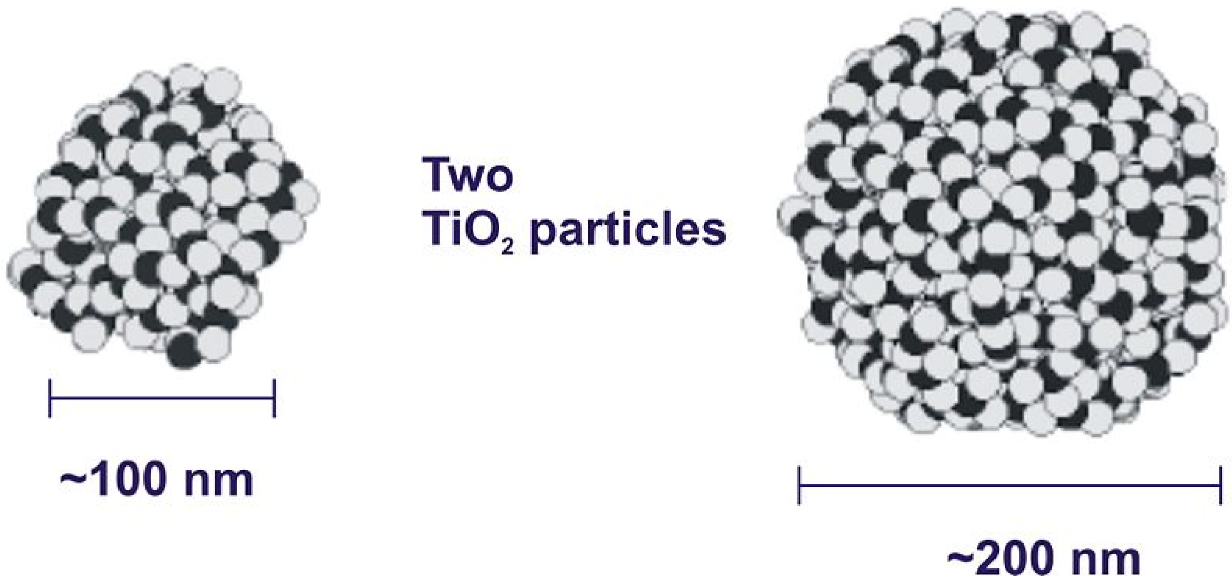


FIGURE 2.30

Inorganic Ingredients: UV Blocking

• Inorganic Sunscreen Ingredients can also absorb UV rays

- But a different structure leads to a different absorption mechanism
- Absorb consistently through whole UV range up to ∼ 380 nm
- How is the absorption pattern different than for organics?

If inorganic sunscreen ingredients block UVA light so well, why doesn't everybody use them?

Appearance Matters

• Traditional inorganic sunscreens appear white on our skin

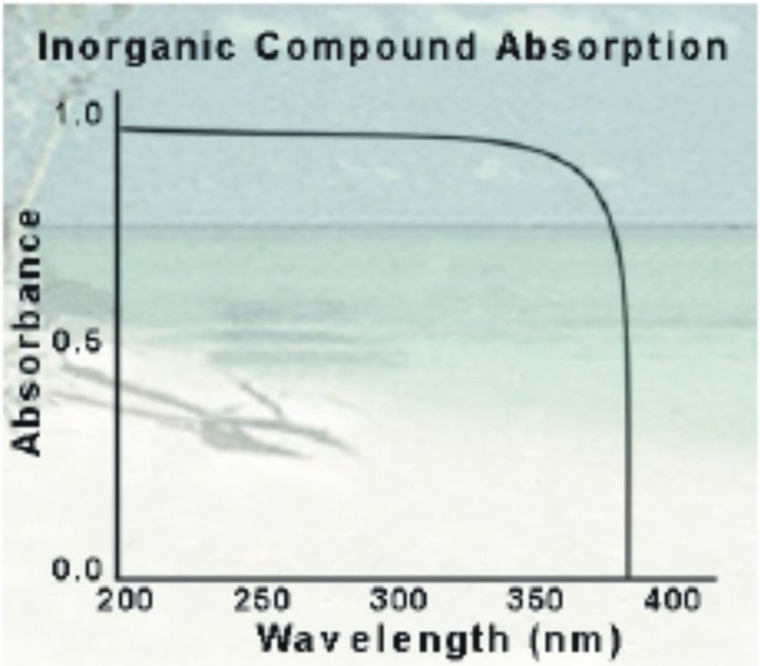


FIGURE 2.31

FIGURE 2.32

FIGURE 2.33

- Many people don't like how this looks, so they don't use sunscreen with inorganic ingredients
- Of the people who do use them, most apply too little to get full protection

Why Do They Appear White? I

- Traditional ZnO and TiO_2 clusters are large
  - $(> 200 \text{ nm})$
- Large clusters can scatter light in many different directions
- Maximum scattering occurs for wavelengths twice as large as the cluster
  - $\lambda > 400$ nm
  - This is **visible** light!

Why Do They Appear White? II

Light eventually goes in one of two directions:

1. Back the way it came (back scattering)

- Back-scattered light is reflected

2. Forwards in the same general direction it was moving (front scattering)

- Front-scattered light is transmitted

Why Do They Appear White? III

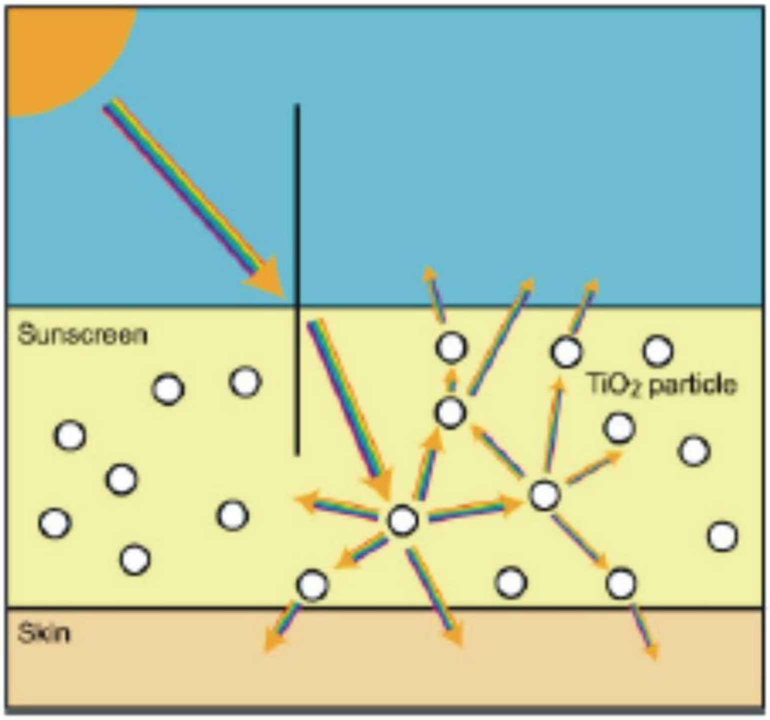


FIGURE 2.34

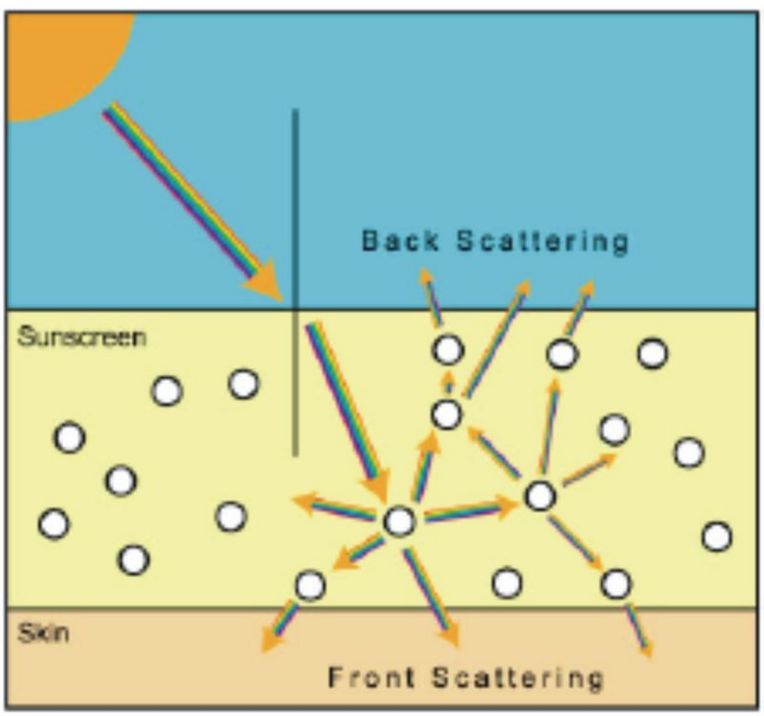


FIGURE 2.35

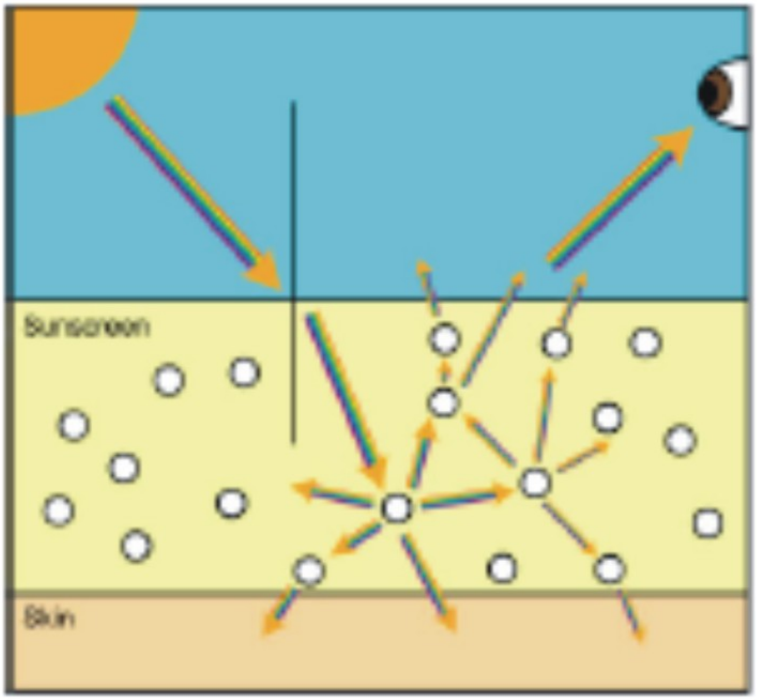
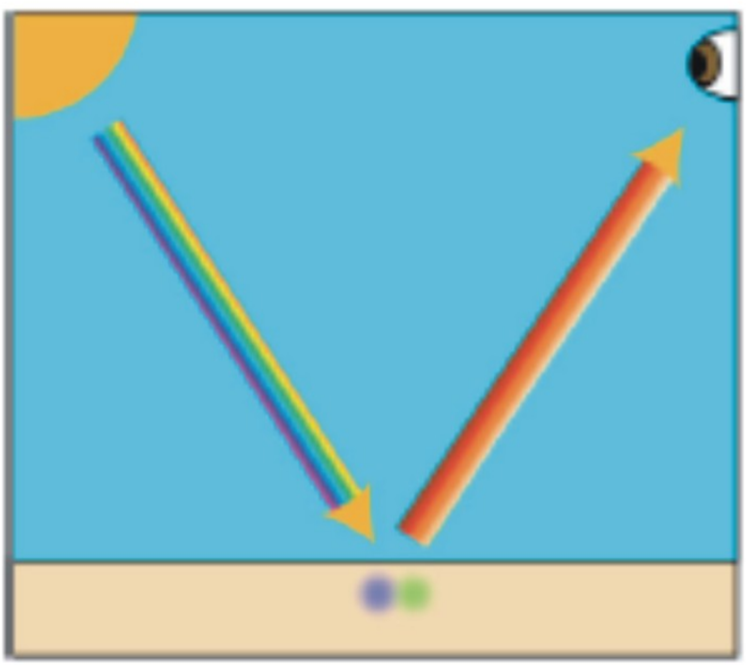


FIGURE 2.36



- When reflected visible light of all colors reaches our eyes, the sunscreen appears white
- This is very different from what happens when sunlight is reflected off our skin directly
  - Green/blue rays absorbed
  - Only red/brown/yellow rays reflected

Why don't organic sunscreen ingredients scatter visible light?

FIGURE 2.37

Organic Sunscreen Molecules are Too Small to Scatter Visible Light

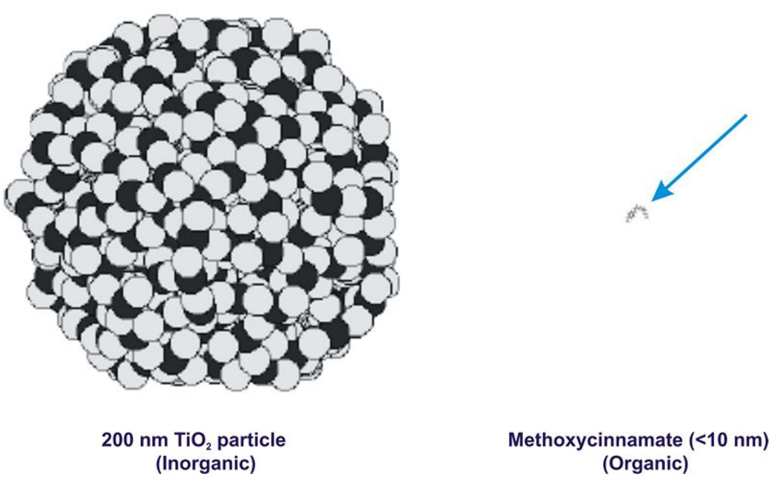


FIGURE 2.38

What could we do to inorganic clusters to prevent them from scattering visible light?

Nanosized Inorganic Clusters

- Maximum scattering occurs for wavelengths twice as large as the clusters

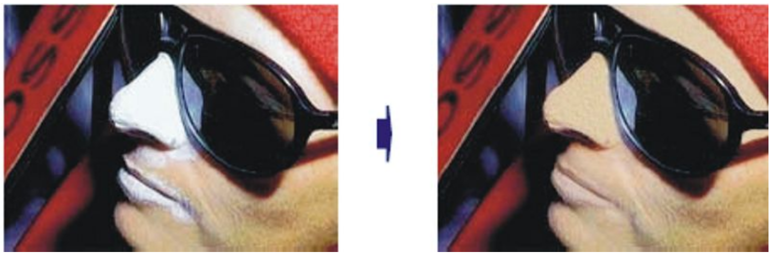


FIGURE 2.39

- Make the clusters smaller (100 nm or less) and they won't scatter visible light

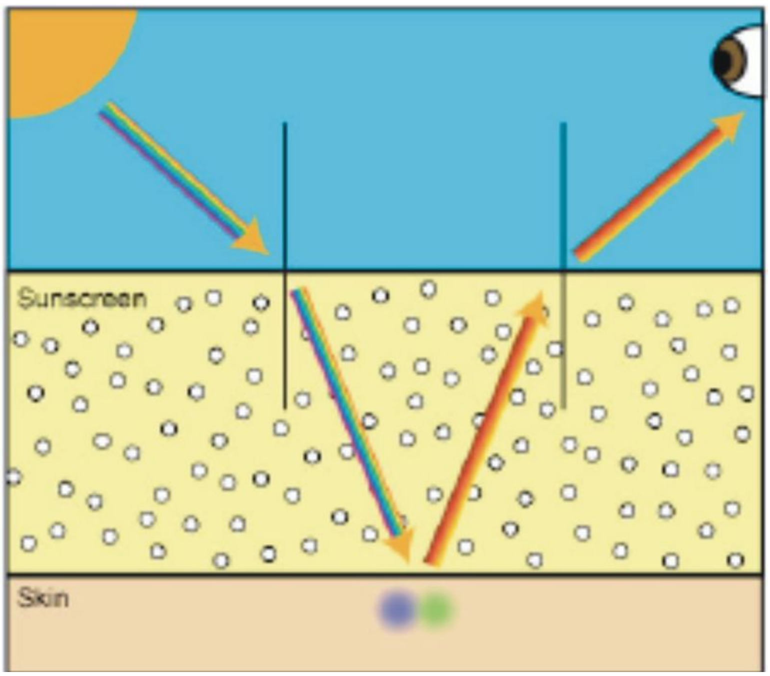


FIGURE 2.40

Nano-Sunscreen Appears Clear

Let's Look at Some Real Data. . .

- Three sunscreens were tested for reflection (backscattering) with different wavelengths of light
  - One contains nanosized inorganic ingredients
  - One contains traditional inorganic ingredients
  - One contains organic ingredients
- Answer the following questions for each sunscreen:

1. Will it appear white or clear on your skin?
2. What size (approximately) are the molecules / clusters?
3. Can we tell how good a UV blocker it is from this graph? Why/ why not?

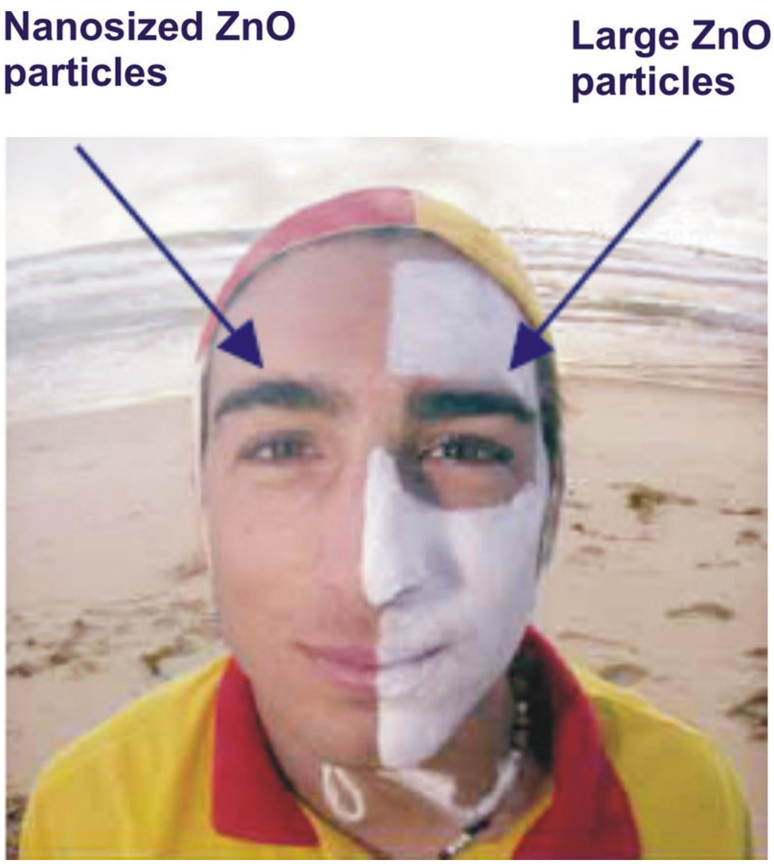


FIGURE 2.41

4. Which one of the sunscreens is it? How do you know?

Light Reflected by Three Sunscreens

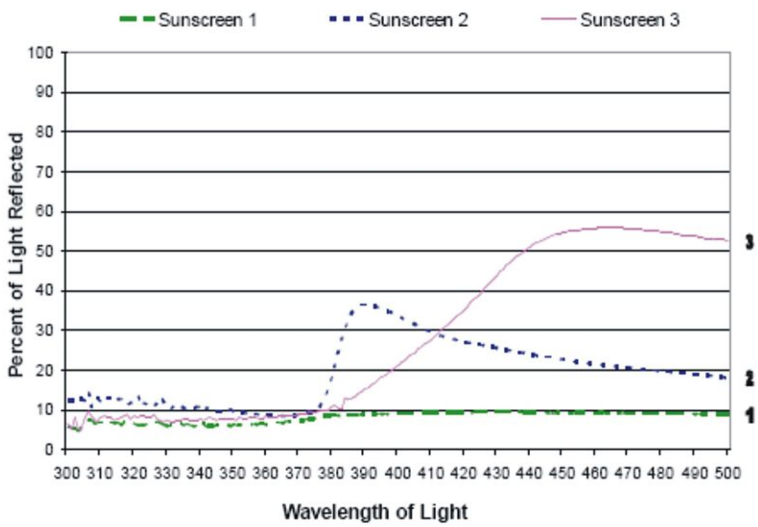


FIGURE 2.42

TABLE 2.25: In Summary I

	Organic Ingredients	Inorganic Ingredients(Nano)	Inorganic Ingredients(Large)
Structure	Individual molecule	Cluster $\sim$ 100 nm in diameter	Cluster $>$ 200 nm in diameter
Interaction w/ UV light	Absorb specific λ of UV light	Absorb all UV $<$ critical λ	Absorb all UV $<$ critical λ
Absorption Range	Parts of UVA or UVB spectrum	Broad spectrum, both UVA and UVB	Broad spectrum, both UVA and UVB
Interaction w/Vis light	None	None	Scattering
Appearance	Clear	Clear	White

In Summary II

- Nanoparticle sunscreen ingredients are small inorganic clusters that:
  - Provide good UV protection by absorbing most UVB and UVA light
  - Appear clear on our skin because they are too small to scatter visible light

Essential Questions: Time for Answers

1. What are the most important factors to consider in choosing a sunscreen?
2. How do you know if a sunscreen has "nano" ingredients?
3. How do "nano" sunscreen ingredients differ from other ingredients currently used in sunscreens?

Teacher Notes

Overview

FIGURE 2.43

This series of slides discusses the basics of sunscreens including their history, types, mechanism for blocking UV light (absorption), appearance (due to scattering) and challenges to providing effective protection. The final slide asks students to use what they've learned to answer the three driving questions for the unit.

Slide 14 includes an optional demo that shows how selective absorption of UV light by certain chemicals used in printing money is serves as an anti-counterfeiting measure. If you choose to do this demo you will need:

- One or more UV lights of any size (several options are available from Educational Innovations at www.teachersource.com)
- Different kinds of paper currency (these must be relatively recently printed; Euros and Canadian bills work particularly well)

Slide 1: Title Slide

Slide 2: What do Sunscreens Do?

This slide is designed to get students thinking about how sunscreens protect our skin. Have students brainstorm ideas about what might happen to the UV rays when they encounter the sunscreen. Ask them how they could test their ideas to see if they are correct.

Slide 3: Light Blocking

The $T+R+A=100\%$ equation is based on the conservation of energy. All incoming light (energy) must be accounted for. It either passes through the material, is sent back in the direction from which it came or is absorbed by the material.

Analogy: The $R+T+A=100\%$ equation can be thought of in terms of baseball. When a pitcher throws the ball towards the batter, three things can happen. The batter can hit the ball (reflection), the catcher can catch the ball (absorption), or the ball can pass by both of them (transmission).

Slide 4: If we know that sunscreens block UV light from reaching our skin does that tell us whether they

absorb or reflect the light? (Question Slide)

Have your students brainstorm ideas about we could figure out what happens to the light. You may need to remind them that the question asks about UV light (which is not visible to the human eye). Assuming we had a UV light detector, where would we want to put it and what would we expect it to measure for each possible scenario (absorption and reflection)?

Slide 5: Sometime More Experiments Are Needed

A key point of this slide is that there are often multiple valid theoretical explanations for experimental data; to find out which works best, additional experiments are required.

For example, it is well known that sunscreens "block" UV light, but this could be viably explained by either absorption or reflection.

To find out which explanation was a better fit for the "blocking" phenomenon, we conducted an experiment in which we prepared a series of glass slides covered with sunscreens. We shone UV light on the sunscreens and placed UV light detectors both on the other side of the slide (to measure transmitted light) and next to the original light source (to measure reflected light). Little reflected or transmitted UV light was detected, so we can infer from $T+R+A = 100\%$ that the sunscreen is absorbing the UV light.

Note that it is often possible to engineer useful materials with an incomplete understanding of their properties. In this example we can design sunscreens that provide effective protection against UV light without knowing whether they do so via absorption or reflection.

Slide 6: A Brief History of Sunscreens: The Beginning

Sunscreens were developed to meet a specific and concrete need: prevent soldiers from burning when spending long hours in the sun. Scientists applied their knowledge of how light interacts with certain chemicals to develop products to meet this need.

The division of the continuous UV spectrum into UVA and UVB categories is somewhat arbitrary. The UVB range is talked about as starting at around $280-290$ nm at the lower end and ending around $310-320$ nm at the upper end.

Slide 7: A Brief History of Sunscreens: The SPF Rating

SPF (Sunscreen Protection Factor) values are based on an "in-vivo" test (done on human volunteers) that measures the redness of sunscreen-applied skin after a certain amount of sun exposure.

SPF <u>used</u> to be thought of a multiplier that can be applied to the time taken to burn, but this is not done anymore because there are so many individual differences and other variables that change this equation (skin type, time of day, amount applied, environment, etc.)

The FDA recommends always using sunscreens with an SPF of at least 15 and not using sunscreen as a reason to stay out in the sun longer. Remind students that no sunscreen can prevent all possible skin damage.

Common Student Question: Is it true that sunscreens above SPF 30 don't provide any extra protection?

Answer: No, this is not true. However, since SPF is not based on a linear scale, a sunscreen with an SPF of 40 does not provide twice as much protection as a sunscreen with an SPF of 20 . Even though you don't get double the protection, you do get some additional protection and so there is added value in using SPFs above 30 .

In the past the FDA only certified SPFs up to 30 but didn't confirm the reliability of higher claims by sunscreen manufacturers. Recently, due to improvement in testing procedures, the FDA had proposed certifying results up to and SPF of 50 .

Slide 8: A Brief History of Sunscreens: The UVA Problem

Since there is no immediate visible effect, it is relatively recently that we have come to understand the dangers of UVA rays. In August 2007, the FDA proposed a UVA rating to be included on sunscreen labels; as of December 2007, the proposal was still under discussion. If the FDA proposal is passed, sunscreen manufacturers will have 18 months to comply with the new labeling requirements.

Creating a rating for UVA protection has been difficult for two reasons:

1. Since UVA radiation does not lead to immediate visible changes in the skin (such as redness) what should be the outcome measure? Is it valid to do an "in-vitro" (in a lab and not on a human) test? (*The FDA proposal includes both*)
2. How should the UVA protection level be communicated to consumers without creating confusion (with the SPF and how to compare / balance the two ratings)? (*The FDA proposal uses a* $4-$ *star system*)

Creating a UVA blocking rating is important since without immediate harmful effects, people are not likely to realize that they have not been using enough protection until serious long term harm has occurred.

Slide 9: How do you know if your sunscreen is a good UVA blocker? (Question Slide)

Have your students brainstorm ideas about ways to tell if a sunscreen is a good UVA blocker.

Slide 10: Know Your Sunscreen: Look at the Ingredients

"Formulating" a sunscreen is the art of combing active and inactive ingredients together into a stable cream or gel product. One of the important challenges here is creating a stable suspension with even ingredient distribution. If the active ingredients clump together in large groups then the sunscreen provides strong protection in some areas and little protection in others.

Analogy: Students may be familiar with the suspension issue as it relates to paint. If paint has been sitting for a while and it is used directly, a very uneven color is produced. This is why we stir (or shake) paint before using in order to re-suspend the particles.

Another issue in sunscreen formulation is trying to create a product that customers will want to buy and use. Qualities such as smell, consistency and ease of rubbing into the skin all play a role in whether or not a sunscreen will be used and whether it will be used in sufficient quantity.

Slide 11: Sunscreen Ingredients Overview

This slide is an advance organizer for the content of the rest of the slide set. You may wish to give your students the Overview of Sunscreen Ingredients: Student Handout at this point to refer to during the rest of the presentation.

You do not need to discuss the details of each cell at this point in the presentation, simply point out that organic and inorganic ingredients have several different properties that will be discussed. All of the content of the table is explained in detail in the following slides.

Slide 12: Organic Ingredients: The Basics

The full name of the compound shown is octyl methoxycinnamate (octyl refer to the eight carbon hydrocarbon tail shown on the right side of the molecule) but it is commonly referred to as octinoxate or OMC.

Slide 13: Organic Ingredients: UV Blocking

When a molecule absorbs light, energy is converted from an electromagnetic form to a mechanical one (in the form of molecular vibrations and rotations). Because of the relationship between molecular motion and heat, this is often referred to as thermal energy.

The process of releasing the absorbed energy is called relaxation. While atoms which have absorbed light simply re-emit light of the same wavelength/energy, molecules have multiple pathways available for releasing the energy. Because of the many vibrational and rotational modes available, there are many choices for how to relax. Since these require smaller energy transitions than releasing the energy all at once, they provide an easier pathway for relaxation – this is why the energy absorbed from the UV light is released as harmless (low energy) IR radiation.

Slide 14: Organic Ingredients: Absorption Range

Light absorption by molecules is similar to the emission of light by atoms with three key differences:

- Light is captured instead of released.
- Molecules absorb broader bands of wavelengths than atoms because there are multiple vibrational and rotational modes to which they can transition (for more details on molecular absorption concepts, see the Lesson 3 PPT and teacher notes).
- There are multiple pathways for relaxation – the light emitted does not have to be the same wavelength as the light absorbed.

Different molecules have different peak absorption wavelengths, different ranges of absorption and differences in how quickly absorption drops off ("fat" curves as compared to "skinny" ones). It is important to realize that even within a molecule's absorption range, it does not absorb evenly and absorption at the ends of the range is usually low. For example, octyl methoxycinnamate has an absorption range of $295-350$ nm , but we would not expect it to be a strong absorber of light with a wavelength of 295 nm .

UV Absorption Demonstration: As one effort to prevent the circulation of counterfeit currency, bills are often printed with special chemicals that absorb specific wavelengths of UV light (this occurs because the energy of these UV rays matches the difference between the molecule's energy levels). When one of these bills is held under a UV light, these molecules absorb the UV light and reemit purple light in the visible spectrum that we can see (note that that the remitted light is <u>not</u> UV light which is not visible to the human eye). You can demonstrate this effect for your students by turning off the classroom lights and shining a UV light on different kinds of bills and watching the printed designs appear (these must be relatively recently printed; Euros and Canadian bills have particularly interesting designs). If you have two UV lights of different wavelengths, you may even be able to see two different designs due to the selective absorption of the different molecules used in the printing.

Slide 15: Organic Ingredients: Absorbing UVA / UVB

Many organic ingredients block "shortwave" UVA light (also called UVA 2 light and ranging from ~ 320 to 340 nm) but not "longwave" UVA light also called UVA 1 light and ranging from ~ 340 to 400 nm). Up till 2006, avobenzone was the only organic ingredient currently approved by the FDA that is a good blocker of longwave UVA light.

Slide 16: Breaking News

In the summer of 2006, the FDA approved Ecamsule (Mexoryl SX), a new sunscreen ingredient designed to absorb UVA rays. One benefit of this ingredient is that it is photostable (many sunscreens are degraded by the sun), but since it is water soluble, it does not provide protection in the water.

This is the first new ingredient to be approved by the FDA since 1998; however it has been approved in Europe since 1991. There is a great deal of pressure on the FDA to approve several other sunscreen ingredients that are already approved in Europe.

Graph Q #38; A for students:

- What does the $y-$ axis shows? (% absorption)
- What kinds of wavelengths does this ingredient absorb? (UVA up to ~ 360 nm)
- Is this an organic ingredient? (Yes)
- How do you know? (Molecular structure with carbon, hydrogen, and nitrogen)

Slide 17: How are inorganic sunscreen ingredients different from organic ones? How might this affect the way they block UV light? (Question Slide)

Have your students brainstorm how inorganic sunscreens might be different from organic ones and how this might affect the way they block UV light.

Slide 18: Inorganic Ingredients: The Basics

Inorganic compounds are described by a formula unit instead of a molecular formula. The big difference is that while a molecular formula tells you exactly how many of each kind of atom are bonded together in a molecule; the formula unit only tells you the ratio between the atoms. Thus while all molecules of an organic substance will have exactly the same number of atoms involved (and thus be the same size), inorganic clusters can be of any size as long as they have the correct ratio between atoms. This occurs because inorganic substances are held together by ionic, not covalent bonds.

You may want to review some of the basics of bonding in inorganic compounds (electrostatic attraction between ions) as opposed to bonding in organic molecules (electron sharing via covalent bonds) with your students here.

Slide 19: Inorganic Ingredients: Cluster Size

Note: the proper scientific name for TiO_2 is "titanium (IV) oxide", but the older name "titanium dioxide" is more commonly used.

This slide is a re-emphasizes the difference between a molecular formula and the formula unit of an inorganic substance. While the molecular formula indicates the actual number of atoms that combine together to form a molecule, the formula unit indicates the ratio of atoms that combine together to form an inorganic compound. Molecules are always the same size whereas inorganic compounds can vary in the number of atoms involved and thus the size of the cluster.

Common Confusion: Inorganic compound clusters are often referred to informally as "particles". Students often confuse this use of the word particle with the reference to the sub-atomic particles (proton, electrons and neutrons) or with reference to a molecule being an example of a particle.

Slide 20: Inorganic Ingredients: UV Blocking

When an inorganic compound absorbs light, energy is converted from an electromagnetic form to a mechanical one (kinetic energy of electrons). The excited electrons use this kinetic energy to "escape" the attraction of the positively charged nuclei and roam more freely around the cluster.

Because there are so many more atoms involved in an inorganic compound than in a molecule, there are also many more different energy values that electrons can have (students can think of these loosely as how "free" the electrons are to move about the cluster; how far from their original position they can roam). The greater number of possible energy states means that a greater range of wavelengths of UV light can be absorbed leading to the broader absorption spectrum shown in the graph.

Slide 21: If inorganic sunscreens ingredients block UVA light so well, why doesn't everybody use them? (Question Slide)

Have your students brainstorm reasons why sunscreen manufacturers and consumers might not want to use inorganic sunscreen ingredients.

Slide 22: Appearance Matters

One of the major reasons that people have not used inorganic ingredients in the past is because of their appearance. Before we knew how dangerous UVA rays were, sunscreens with organic ingredients seemed to be doing a good job (since they do block UVB rays).

Applying too little sunscreen is very dangerous because this reduces a sunscreen's blocking ability while still giving you the impression that you are protected. In this situation people are more likely to stay out in the sun longer and then get burned.

Slide 23: Why Do They Appear White? I

Scattering is a physical process that depends on cluster size, the index of refraction of the cluster substance and the index of refraction of the suspension medium. No energy transformations occur during scattering (like they do in absorption); energy is simply redirected in multiple directions. The wavelengths (and energy) of light coming in and going out are always the same.

Maximum scattering occurs when the wavelength is twice as large as the cluster size. Since traditional inorganic sunscreen ingredients have diameter > 200 nm , they scatter light which is > 400 nm in diameter – this is in the visible spectrum.

Slide 24: Why Do They Appear White? II

Multiple scattering is a phenomenon of colloids (suspended clusters). When light is scattered, at the micro level it goes in many directions. At the macro level, it eventually either goes back the way it came or forwards in the same general direction it was moving. These are known as back- and front- scattering and they contribute to reflection and transmission respectively.

Note that the formula presented earlier (Reflection + Transmission + Absorption = 100%) still holds. Scattering simply contributes to the "reflection" and "transmission" parts of the equation. (For more details on scattering concepts, see the Lesson 4 PPT and teacher notes).

Slide 25: Why Do They Appear White? III

The scattering of visible light by ZnO and TiO_2 is the cause of the thick white color seen in older sunscreens. When the different colors of visible light are scattered up and away by the sunscreen, they reach our eyes. Since the combination of the visible spectrum appears white to our eyes, the sunscreen appears white.

Depending on your students' backgrounds, you may want to review how white light is a combination of all colors of light.

You may also want to discuss how the pigment in our skin selectively absorbs some colors (wavelengths) of visible light, while reflecting others. This is what usually gives our skin its characteristics color. Different pigments (molecules) absorb different wavelengths; this is why different people have different color skin.

Slide 26: Why don't organic sunscreen ingredients scatter visible light? (Question Slide)

Have your students brainstorm reasons why organic sunscreen ingredients don't scatter visible light.

Slide 27: Organic Sunscreen Molecules are Too Small to Scatter Visible Light

Traditional inorganic clusters are usually 200 nm or larger, causing scattering in the visible range ($400-700$ nm) . Organic sunscreen molecules are smaller than 10 nm (usually $1-20$ Angstroms) and thus do not scatter in the visible range.

You may want to talk about how while the individual organic sunscreen molecules are very small compared to inorganic sunscreen clusters (many formula units ionically bonded together creating a large cluster) and the wavelengths of visible light, they are big compared to many of the simple molecules that students are used to studying, such as water or hydrochloric acid.

How big or small something seems is relative to what you are comparing it to. In this case, we are comparing sunscreen ingredients with the size of the wavelength of light.

Slide 28: What could we do to inorganic clusters to prevent them from scattering visible light? (Question Slide)

Have your students brainstorm what we could do to inorganic clusters to prevent them from scattering light. If students say "make them smaller", ask them how small the clusters would need to be in order to not scatter visible light.

Slide 29: Nanosized Inorganic Clusters

When visible light is not scattered by the clusters, it passes through the sunscreen and is reflected by our skin (blue and green rays are absorbed by pigments in the skin and the red, yellow and orange rays are reflected to our eyes giving skin its characteristic color).

Changing the size of the cluster does not affect absorption since this depends on the energy levels in the substance which are primarily determined by the substance's chemical identity.

Discussion Question for Students: Is it good or necessary to block visible light from reaching our skin?

Answer: Visible light has less energy than UVA light and is not currently thought to do any harm to our skin thus there is no need to block it. Think about human vision: visible light directly enters our eyes on a regular basis without causing any harm.

If you are not planning on doing Lesson 4: You may want to demo the sunscreen animations for your class at this point. The animations are available at http://nanosense.org/activities/clearsunscreen/index.html and are explained in the Sunscreens #38; Sunlight Animations: Teacher Instructions #38; Answer Key in Lesson 4.

Slide 30: Nano-Sunscreen Appears Clear

This slide shows the difference in appearance between traditional inorganic and nanosunscreens.

Slide 31: Let's Look at Some Real Data...

At this point you should hand out the Light Reflection by Three Sunscreens: Student Worksheet. You can either have students work on it in groups or proceed to the next slide and work through the questions as a whole class.

Slide 32: Light Scattering by Three Sunscreens

The following answers are also presented in chart form in the Light Reflection by Three Sunscreens: Teacher Answer Key.

Sunscreen 1

Appearance

- No scattering in the visible range
- Sunscreen appears clear on the skin.

Size

- Since no scattering seen, it is not possible to estimate the size of the molecule from the information in the graph.

UV Blocking

- The graph shows very little reflection in the UV range, however, this doesn't tell us anything because absorption is the main blocking mechanism for UV.
- We would need an absorption or transmission graph in order to determine the UV blocking ability of the sunscreens.
- $T+R+A=1$

Identity

- Virtually no scattering in the visible range indicates organic ingredients.
- Because organic molecules are small compared to the wavelengths of light used, almost no scattering in the visible range occurs and the line is basically flat.
- This sunscreen contains the organic ingredients octinoxate (shown on slides 9 #38; 10) and oxybenzone.
- (The sunscreen is Walgreens SPF 15).

Sunscreen 2

Appearance

- Very limited scattering in the visible range
- Sunscreen appears clear on the skin.

Size

- The sharp drop in the curve at 380 nm is actually due to absorption (if all the light is getting absorbed, it can't be scattered) so we cannot know the exact size of the cluster.
- We only know that the curve would have peaked below 380 nm , so the cluster size is smaller than 190 nm .

UV Blocking

- See general explanation under Sunscreen 1.

Identity

- Low amounts of scattering in the visible range, indicates inorganic ingredients with nanosized clusters.
- Because nanosized clusters are less than half the size of the wavelengths of light used, limited scattering in the visible range occurs.
- This sunscreen contains nanosized zinc oxide.
- (The sunscreen is Skin Ceuticals SPF 30).

Sunscreen 3

Appearance

- Significant scattering in the visible range.
- Sunscreen appears white on the skin.

Size

- Significant scattering in the visible range.
- Sunscreen appears white on the skin.

UV Blocking

- See general explanation under Sunscreen 1.

Identity

- Significant amounts of scattering in the visible range indicates inorganic ingredients with large clusters size.
- Because traditional inorganic ingredient clusters are about half the size of the wavelengths of light used, a great deal of scattering in the visible range occurs.
- This sunscreen contains traditional titanium dioxide.
- (The sunscreen is Bullfrog SPF 45).

Slide 33: In Summary I

If you have not yet given your students the Overview of Sunscreen Ingredients: Student Handout, do so now. Use the handout to review the similarities and differences between the three kinds of ingredients.

Key Similarities #38; Differences:

- Both kinds of inorganic ingredients have the same atoms, structure and UV absorption
- Nano-inorganic clusters are much smaller than the cluster size of traditional inorganic ingredients, thus do not scatter visible light, thus are clear.

Slide 34: In Summary II

The big benefit of nano-sunscreen ingredients is that they combine UVA blocking power with an acceptable appearance.

Slide 35: Essential Questions: Time for Answers

Hand out the Reflecting on the Guiding Questions: Student Worksheet and have students work in pairs to answer it. You may also want to review the questions with the class as a whole.

Light Reflection by Three Sunscreens: Teacher Answer Key

Introduction

Three sunscreens were tested for reflection (back-scattering) with different wavelengths of light:

- One contains nanosized inorganic ingredients
- One contains traditional inorganic ingredients
- One contains organic ingredients

A graph was created to show the percent of light reflected by each sunscreen at different wavelengths and is included in this packet.

Instructions

Use the graph to answer the following questions for each sunscreen in the chart on the next page:

1. Will it appear white or clear on your skin? How do you know?
2. What size (approximately) are the molecules / clusters?
3. Can we tell how good a UV blocker it is from this graph? Why/ why not?
4. Which one of the sunscreens is it? How do you know?

TABLE 2.26: Light Reflection by Three Sunscreens Chart

	Appearance	Size	UV Blocking	Identity (w/ reason)
# 1	No scattering in the visible range Sunscreen appears clear on the skin.	Since no scattering seen, it is not possible to estimate the size of the molecule from the information in the graph.	The graph shows very little reflection in the UV range, however, this doesn't tell us anything because absorption is the main blocking mechanism for UV. We would need an absorption or transmission graph in order to determine the UV blocking ability of the sunscreens. $T+R+A=1$	Virtually no scattering in the visible range indicates organic ingredients. Because organic molecules are small compared to the wavelengths of light used, almost no scattering in the visible range occurs and the line is basically flat. This sunscreen contains the organic ingredients octinoxate (shown on slides 9 & 10) and oxybenzone. (The sunscreen is Walgreens SPF 15).
# 2	Very limited scattering in the visible range Sunscreen appears clear on the skin.	The sharp drop in the curve at 380 nm is actually due to absorption (if all the light is getting absorbed, it can't be scattered) so we cannot know the exact size of the cluster. We only know that the curve would have peaked below 380 nm , so the cluster size is smaller than 190 nm .	See above.	Low amounts of scattering in the visible range, indicates inorganic ingredients with nanosized clusters. Because nanosized clusters are less than half the size of the wavelengths of light used, limited scattering in the visible range occurs. This sunscreen contains nanosized zinc oxide. (The sunscreen is Skin Ceuticals SPF 30)

TABLE 2.26: (continued)

	Appearance	Size	UV Blocking	Identity (w/ reason)
# 3	Significant cattering in the visible range. Sunscreen appears white on the skin.	Because the graph peaks around 450 nm , we would estimate the cluster size to be about 225 nm .	See above.	Significant amounts of scattering in the visible range indicates inorganic ingredients with large clusters size. Because traditional inorganic ingredient clusters are about half the size of the wavelengths of light used, a great deal of scattering in the visible range occurs. This sunscreen contains traditional titanium dioxide. (The sunscreen is Bullfrog SPF 45).

Light Reflected by Three Sunscreens

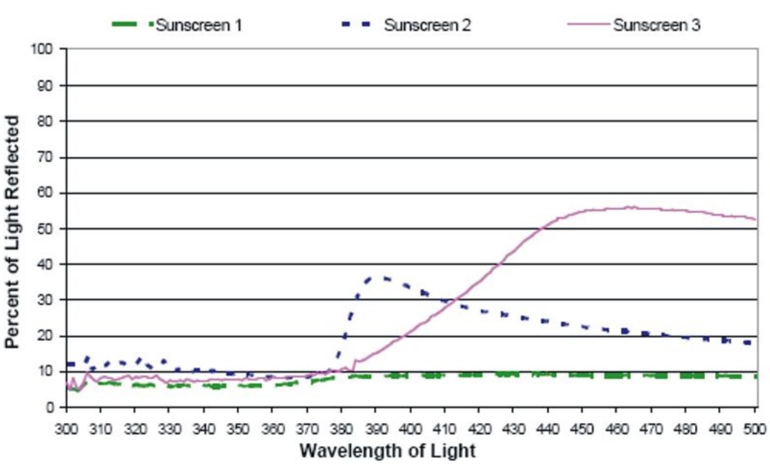


FIGURE 2.44

Reflecting on the Guiding Questions: Teacher Instructions #38; Answer Key

You may want to have your students keep these in a folder to use at the end of the unit, or collect them to see how your students' thinking is progressing. You can also have a group discussion about what students learned from the activity that helps them answer the guiding questions.

Discussion Idea:

For each "What I still want to know" section, have students share their ideas and discuss whether their questions are scientific ones or questions of another sort. Scientific questions are questions about how the natural world operates that can be answered through empirical experiments. Other kinds of questions might be ethical in nature (e.g. do friends have a responsibility to persuade friends to use sunscreen?) or policy questions (e.g. should the FDA endorse the most effective sunscreens?).

Think about the activities you just completed. What did you learn that will help you answer the guiding questions? Jot down your notes in the spaces below.

1. What are the most important factors to consider in choosing a sunscreen?

What I learned in this activity:

Possible Answers:

It is important to choose a sunscreen that provides good protection against both UVA and UVB.

A sunscreen's SPF number tells us how well the sunscreen protects against UVB rays.

Right now there is no regulated measure of UVA protection. Sunscreen labels that claim UVA or "broadband" protection may or may not actually protect against all UVA light.

Until the new FDA UVA rating is approved, the only way to tell how well a sunscreen protects against UVA rays is by looking at the ingredients. Avobenzone and Ecamsule are two organic ingredients that provide protection from some of the UVA range. Zinc Oxide and Titanium Dioxide are two inorganic ingredients that provide protection from almost the whole UVA range.

It is also important to choose a sunscreen that we like in terms of appearance and smell to make sure that we use enough of it to be effective.

What I still want to know:

2. How do you know if a sunscreen has "nano" ingredients?

What I learned in this activity:

Possible Answers:

"Nano" ingredients are smaller versions of traditional inorganic ingredients that go on clear. If a sunscreen contains Zinc Oxide or Titanium Dioxide, but appears clear on our skin, then it likely contains nanoparticles of ZnO or TiO_2 .

What I still want to know:

3. How do "nano" sunscreen ingredients differ from most other ingredients currently used in sunscreens?

What I learned in this activity:

Possible Answers:

Most ingredients currently used in sunscreens are organic ingredients. These are individual molecules that absorb narrow bands of the UVA or UVB spectrum.

"Nano" sunscreen ingredients are inorganic and absorb almost the whole UV spectrum.

"Nano" sunscreen ingredients are inorganic and very similar to traditional inorganic ingredients (large ZnO and TiO_2 clusters) – they are made up of the same kinds of atoms and have the same formula unit, thus they absorb strongly in both the UVA and UVB range up to their cutoff wavelength: 380 nm (ZnO) or 365 nm (TiO_2) .

What I still want to know:

How Sunscreens Block: The Absorption of UV Light

Contents

- How Sunscreens Block: The Absorption of UV Light: Teacher Lesson Plan
- How Sunscreens Block: The Absorption of UV Light: PowerPoint Slides and Teacher Notes
- Reflecting on the Guiding Questions: Teacher Instructions #38; Answer Key

Teacher Lesson Plan

Orientation

This lesson introduces students to the core science behind sunscreen absorption of UV light. This is an advanced topic that requires students to have a background in atomic energy levels, absorption and emission processes.

- The How Sunscreens Block: The Absorption of UV Light PowerPoint focuses on the details of how matter absorbs light. The slides start with the more familiar concept of the emission of light by atoms and progress to absorption of light by atoms, then absorption of light by organic molecules, and finally absorption of light by inorganic compounds. The Absorption Summary Student Handout should help students pull make connections between a chemical's structure and its absorptive properties.
- The Student Reading on Absorption provides more details about this key interaction between light and matter.
- The Reflecting on the Guiding Questions Worksheet asks students to connect their learning from the activities in the lesson to the overall driving questions of the unit.

Essential Questions (EQ)

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

1. What are the most important factors to consider in choosing a sunscreen?
2. How do you know if a sunscreen has "nano" ingredients?
3. How do "nano" sunscreen ingredients differ from most other ingredients currently used in sunscreens?

Enduring Understandings (EU)

Students will understand:

(*Numbers correspond to learning goals overview document*)

1. How the energies of different wavelengths of light interact differently with different kinds of matter.

Key Knowledge and Skills (KKS)

Students will be able to:

(*Numbers correspond to learning goals overview document*)

1. Describe the mechanisms of absorption and scattering by which light interacts with matter.

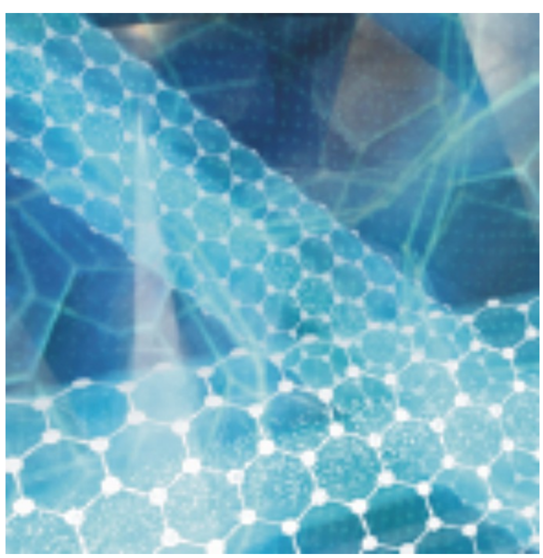
TABLE 2.27: Absorption Timeline

Day	Activity	Time	Materials
	Homework: Absorption of Light by Matter: Student Reading	20 min	Copies of Absorption of Light by Matter: Student Reading

TABLE 2.27: (continued)

Day	Activity	Time	Materials
Day 1 (50 min)	Show How Sunscreens Block: The Absorption of UV Light PowerPoint Slides, using the embedded question slides and teacher's notes to start class discussion. Discuss the readings and any questions students have about the PowerPoint slides.	35 min	How Sunscreens Block: The Absorption of UV Light PowerPoint Slides & Teacher Notes Copies of Absorption Summary: Student Handout Computer and projector
	Have students work individually or in small groups to fill out the Reflecting on the Guiding Questions: Student Worksheet.	5 min	Copies of Reflecting on the Guiding Questions: Student Worksheet
	Bring the class together to have students share their reflections with the class. This is also a good opportunity for you to address any misconceptions or incorrect assumptions from students that you have identified in the unit up till now.	10 min	Reflecting on the Guiding Questions: Teacher Instructions & Answer Key

How Sunscreens Block



The Absorption of UV Light

Prelude: Emission of Light by Atoms

- An e^- falls from a higher energy state to a lower one
  - A photon with the exact energy difference between the levels is released

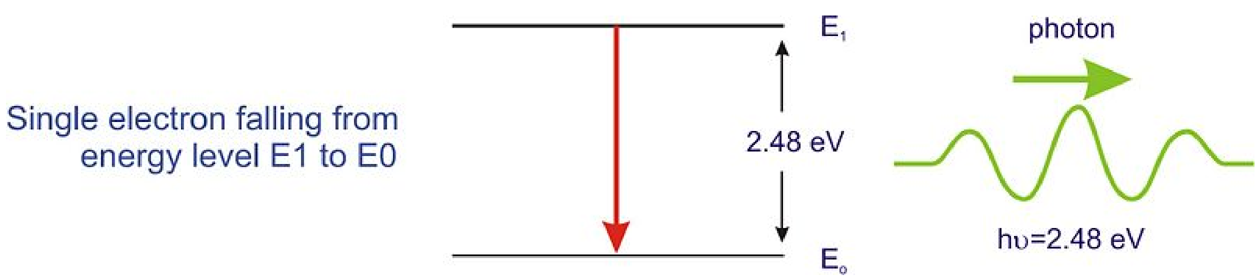


FIGURE 2.45

- Each atom has characteristic energy level transitions which create an atomic spectrum

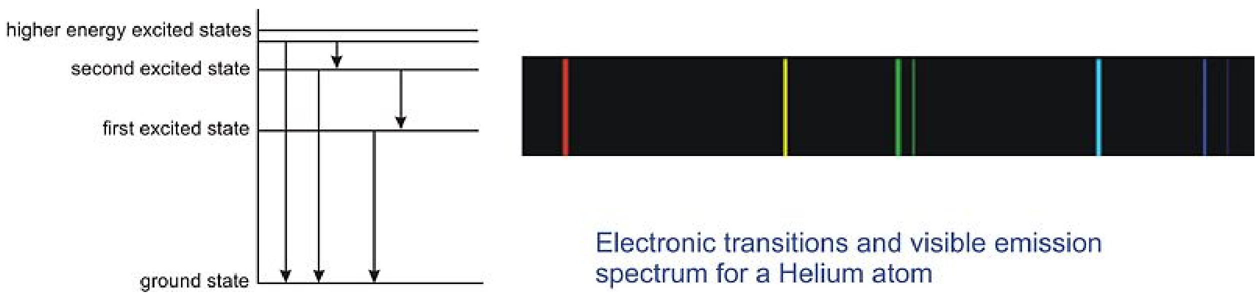


FIGURE 2.46

Prelude: Absorption of Light by Atoms

- Absorption is just the reverse
  - Only a photon with energy exactly corresponding to the energy of transition of an electron can be absorbed

- The different transitions produce absorption spectrums of discrete lines

Prelude: Emission versus Absorption

If atomic absorption produces absorption lines, what do you think molecular absorption look like?

Organic Molecules: Energy Levels

- Molecules have multiple atoms which can vibrate and rotate in relation to each other

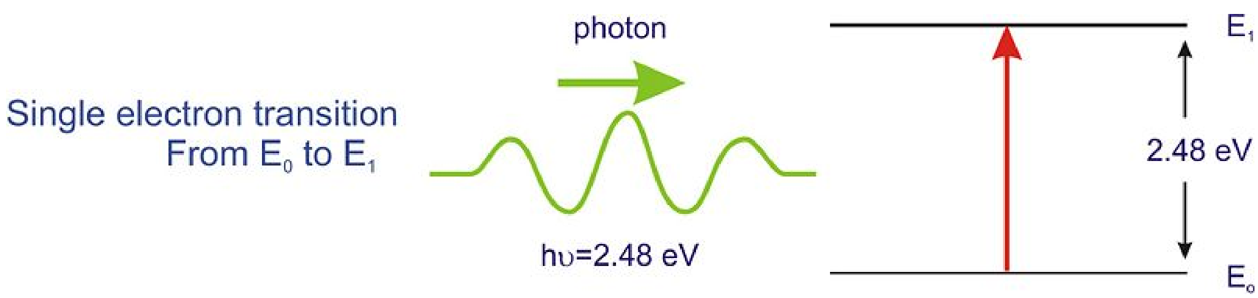


FIGURE 2.47

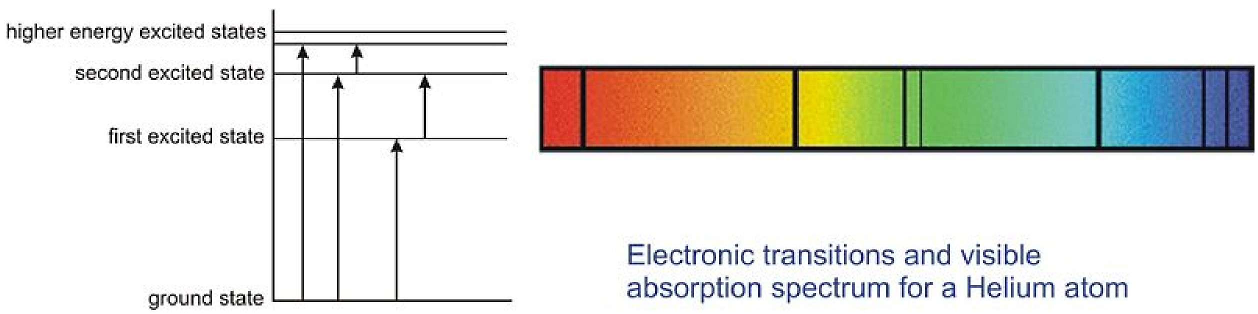


FIGURE 2.48

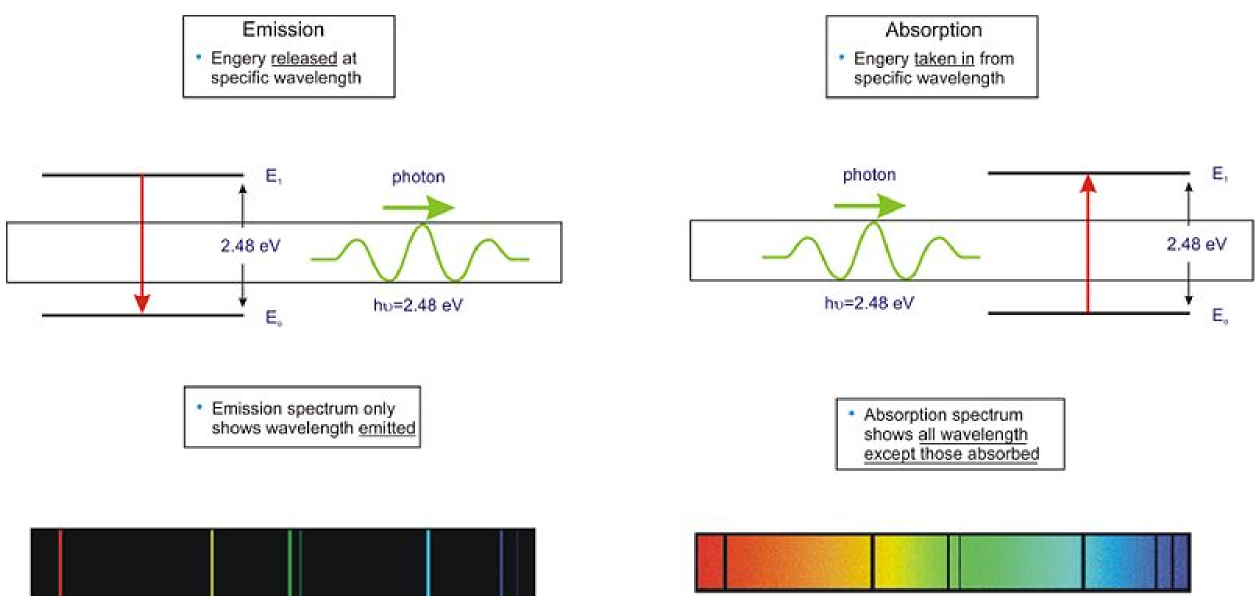


FIGURE 2.49

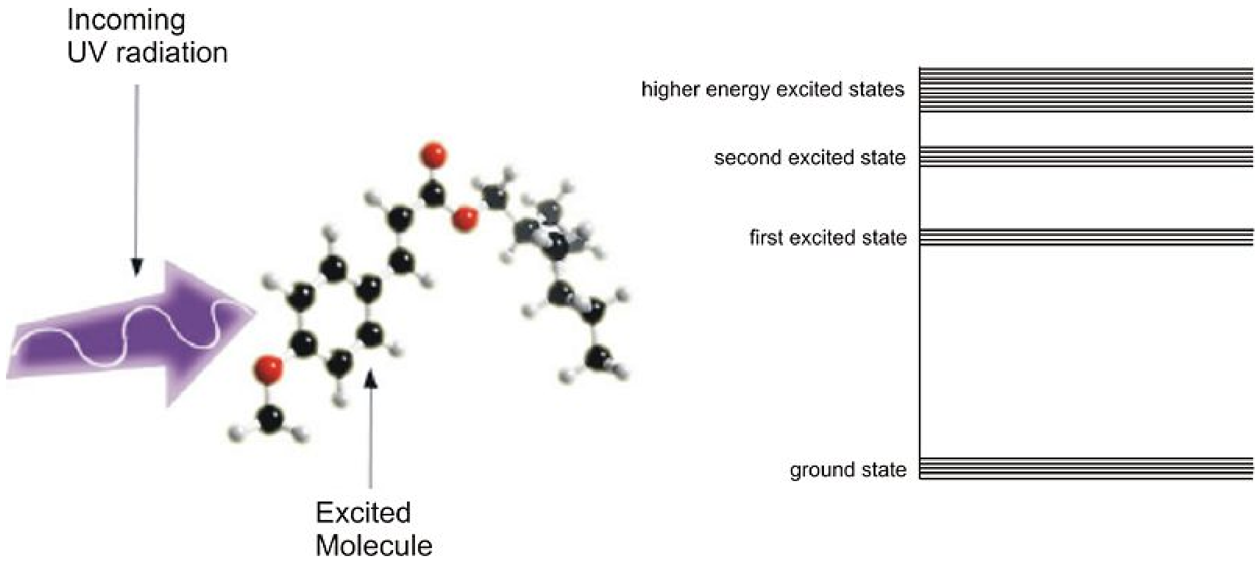


FIGURE 2.50

– Each kind of vibration / rotation = different energy state

- Many more energy transitions possible

Organic Molecules: Absorption

- Many closely spaced energy transitions mean that instead of absorbing exact frequencies of light, molecules absorb groups of frequencies

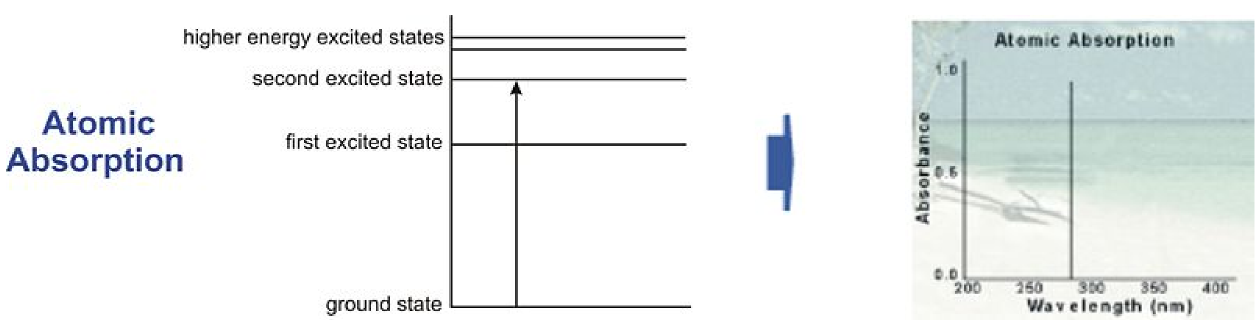


FIGURE 2.51

Organic Molecules: Absorption Curve

- The many closely spaced absorption lines combine to make an absorption band:

- Peak absorption and absorption range vary by molecule

FIGURE 2.52

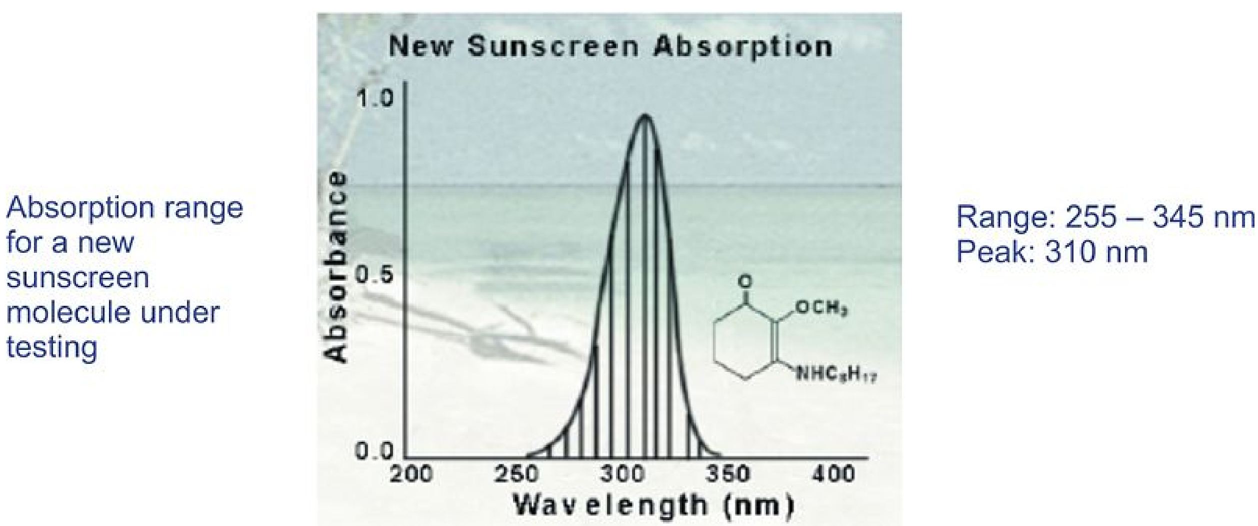


FIGURE 2.53

- Molecules are usually strong UVB or UVA absorbers but not both

Organic Molecules: UV Protection

- Different ingredients are good for blocking different parts of the UV spectrum

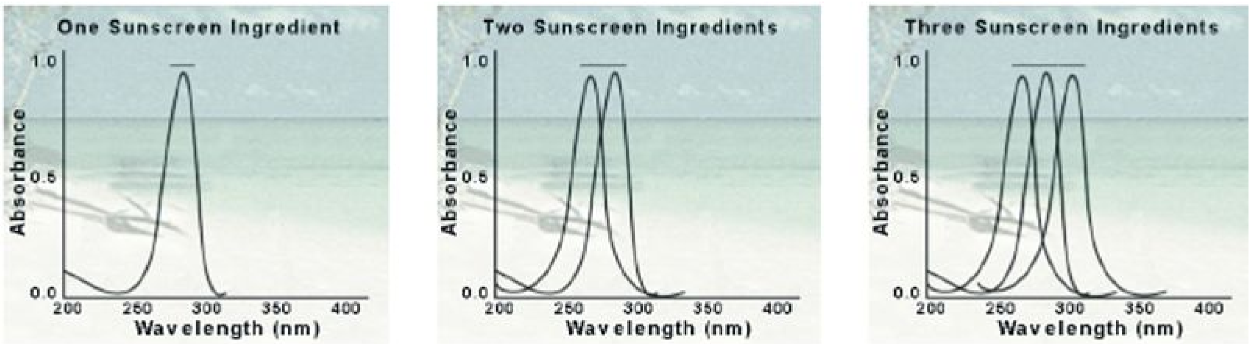


FIGURE 2.54

- Using more than one kind of molecule gives broader protection

How do you think absorption by inorganic compounds might be different than absorption by molecules?

Inorganic Compounds: Energy Levels

- Inorganic ingredients exist as particle clusters
  - Very large number of atoms involved
  - Electrons' energy depends on their position in relation to all of them
- Huge number of different energy levels possible

Inorganic Compounds: Absorption I

- Because the energy levels are so closely spaced, we talk about them together as energy "bands"
  - Normal energy band for electrons (ground states) is called the "valence band"
  - Higher energy band (electrons are more mobile) is called the "conduction band"
- In each band, there are many different energies that an electron can have
  - The energy spacing between the two bands is called the "energy gap" or "band gap"

Inorganic Compounds: Absorption II

- Electrons can "jump" from anywhere in the valence band to anywhere in the conduction band
  - Inorganic Compounds are able to absorb all light with energy equal to or greater than the band gap energy

Inorganic Compounds: Absorption Curve

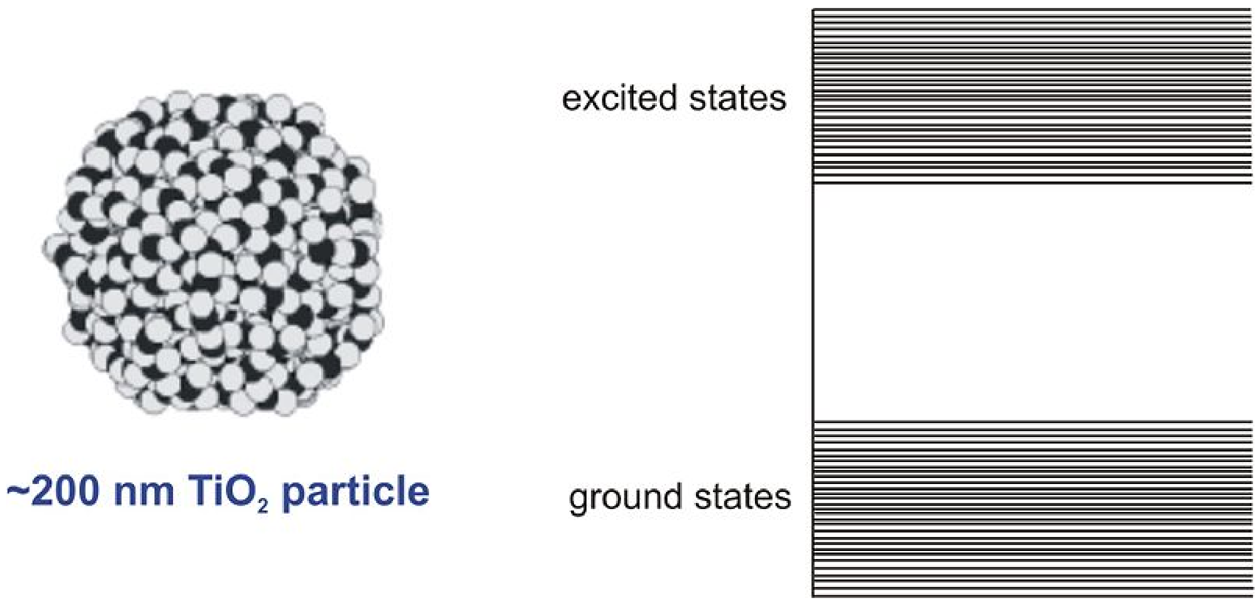


FIGURE 2.55

- This is the same as saying that all light absorbed must have a wavelength equal to or less than the wavelength corresponding to the band gap energy

- Absorption curves have sharp cutoffs at this λ
  - Cutoff λ is characteristic of the kind of compound
  - Doesn't depend on size of the cluster

Inorganic Compounds: UV Protection

- Inorganic Compounds with cut off wavelengths around 400 nm (ZnO and TiO_2) are able to absorb almost the whole UV spectrum
  - Can be the only active ingredient in a sunscreen
  - Can also be combined with other ingredients for reasons such as appearance or cost
  - True for both nano and traditional forms (not dependant on size)

TABLE 2.28: Absorption Summary

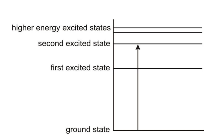
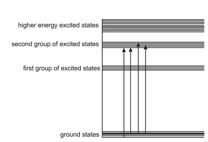
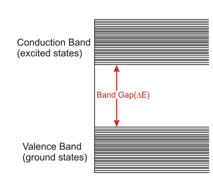
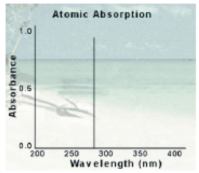
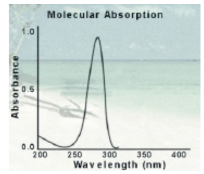
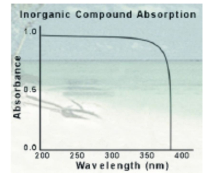
	Atoms	Organic Molecules	Inorganic Compounds
Energy Levels			

TABLE 2.28: (continued)

	Atoms	Organic Molecules	Inorganic Compounds
Absorption Spectrum			

Challenge Question:

Can sunscreens absorb all of the UV light that shines on our skin?

Answer: It Depends I

- The amount of sunscreen applied influences how much of the incoming UV light is absorbed

Answer: It Depends II

- The concentration and dispersion of the active ingredients also influences how much of the incoming UV light is absorbed

Summary

- Active sunscreen ingredients absorb UV light
  - Organic molecules each absorb a specific range of wavelengths determined by their energy level spacing
  - Inorganic compounds absorb all wavelengths less than a critical value (which corresponds to the band gap energy)
- Several practical factors are important to ensure that a sunscreen provides the best possible protection against UV light
  - High concentration of active ingredients
  - Wide dispersion of active ingredients
  - Applying an appropriate amount of sunscreen

Teacher Notes

Overview

This set of slides focuses on the details of how matter absorbs light. The slides start with the more familiar concept of the emission of light by atoms and progress to absorption of light by atoms, then absorption of light by organic molecules, then absorption of light by inorganic compounds.

Slide 1: Title Slide

Slide 2: Prelude: Emission of Light by Atoms

The key concept in this slide is that the energy of the photon released is always equal to an energy difference between energy levels. The characteristic energy of the photon is related to its frequency and wavelength, and if the light is in the visible spectrum, a characteristic color.

The different energy levels relate to the position and movement of electrons with respect to the nuclei.

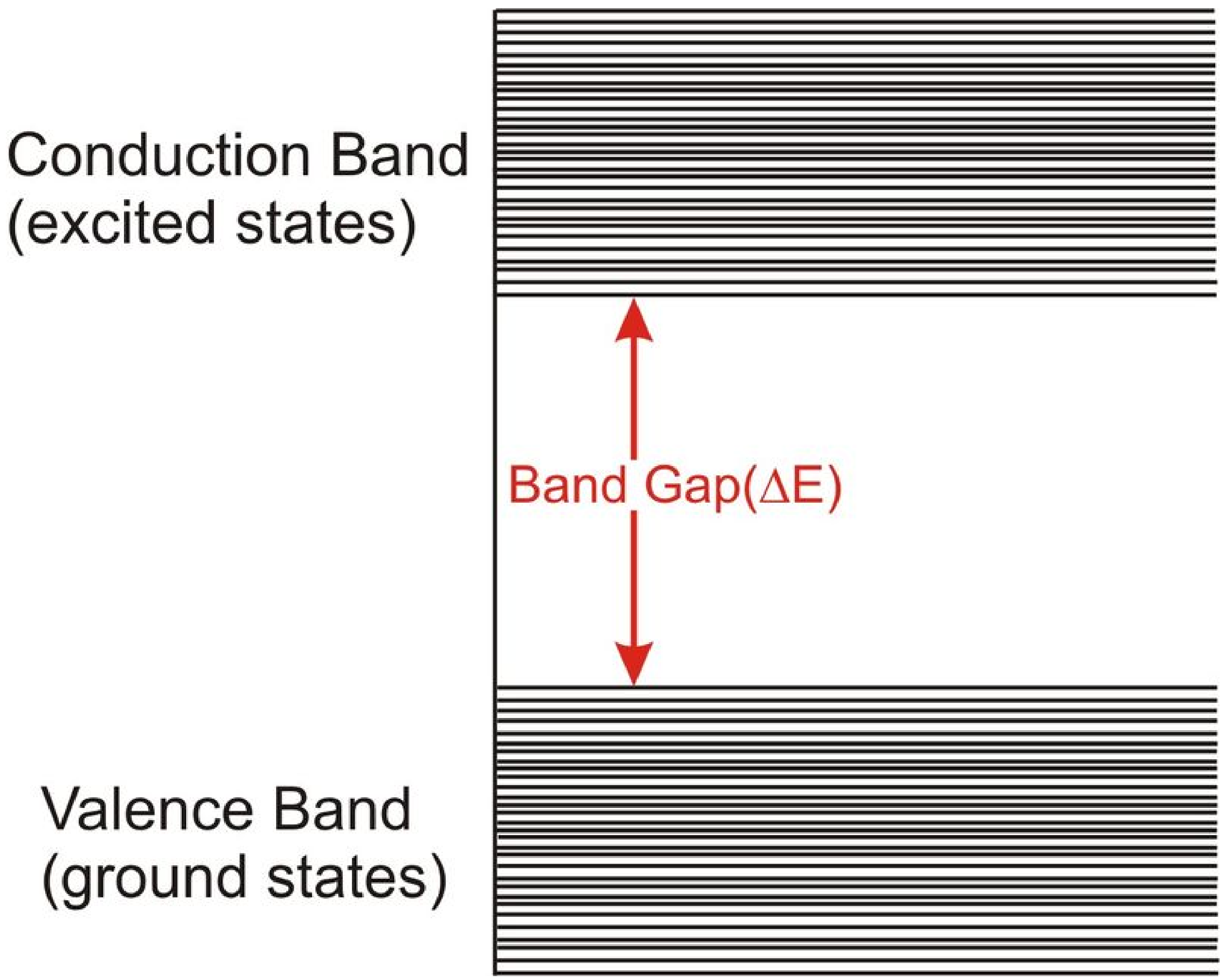


FIGURE 2.56

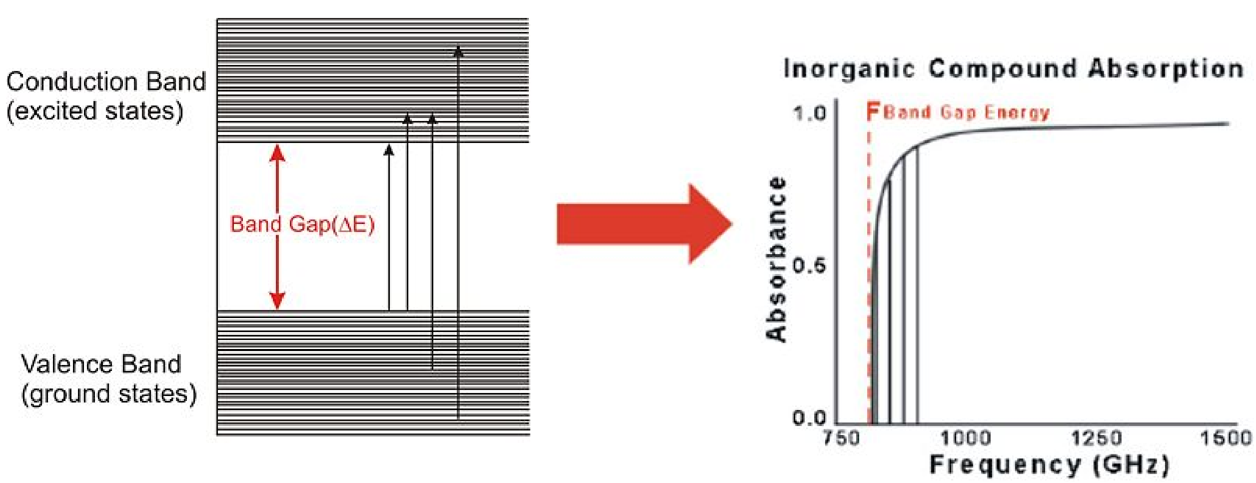
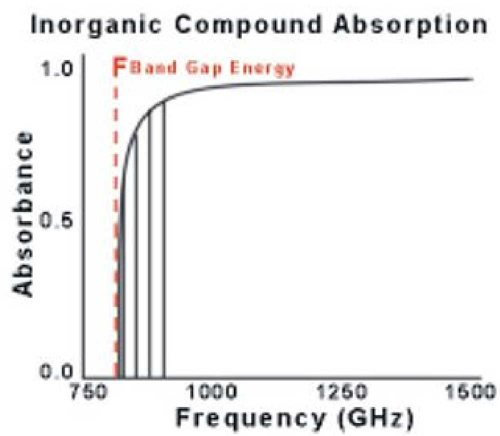


FIGURE 2.57



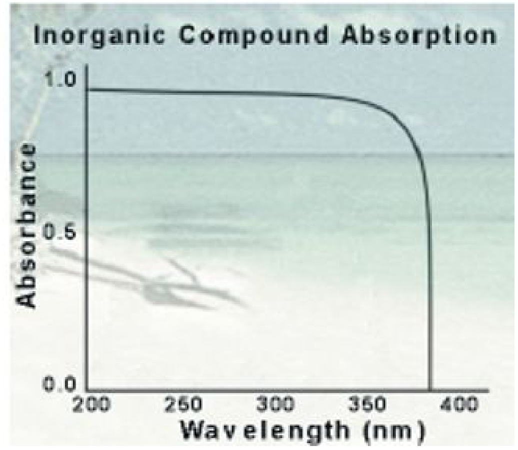


FIGURE 2.58

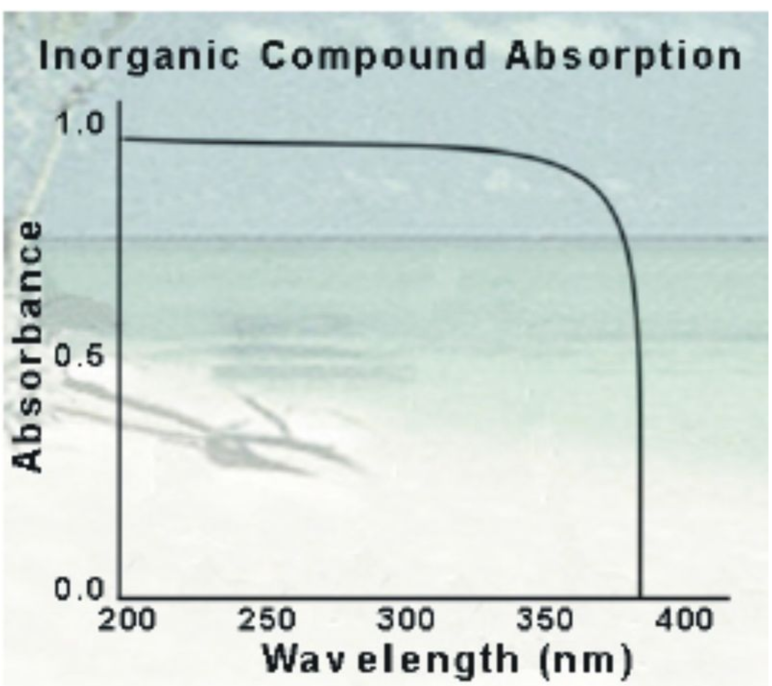


FIGURE 2.59

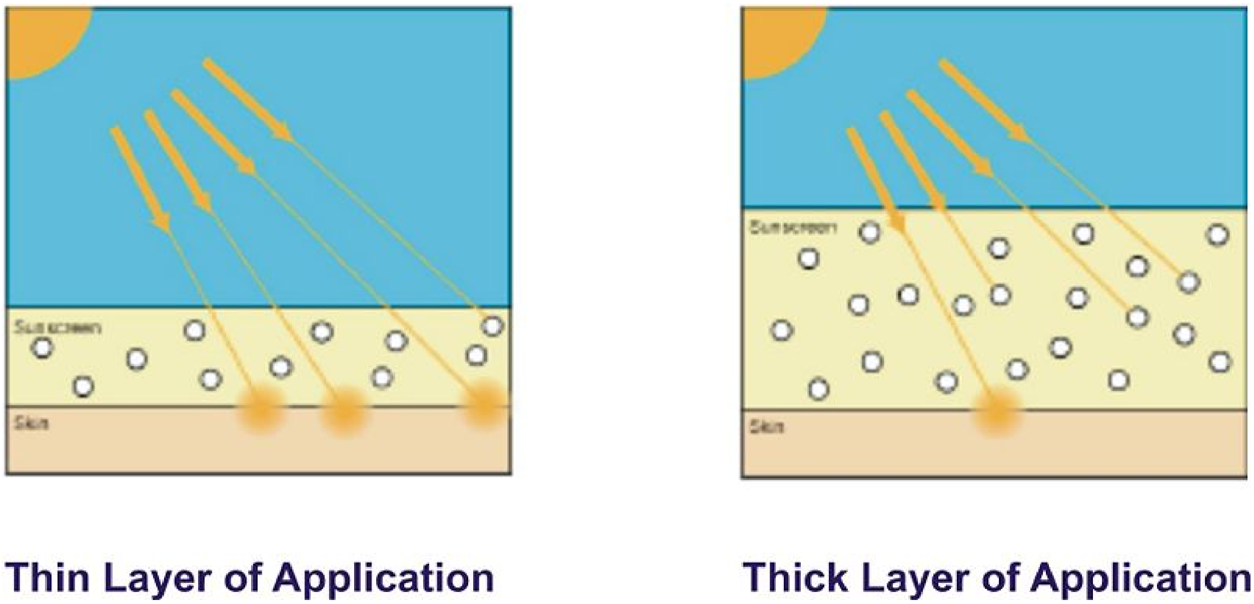


FIGURE 2.60

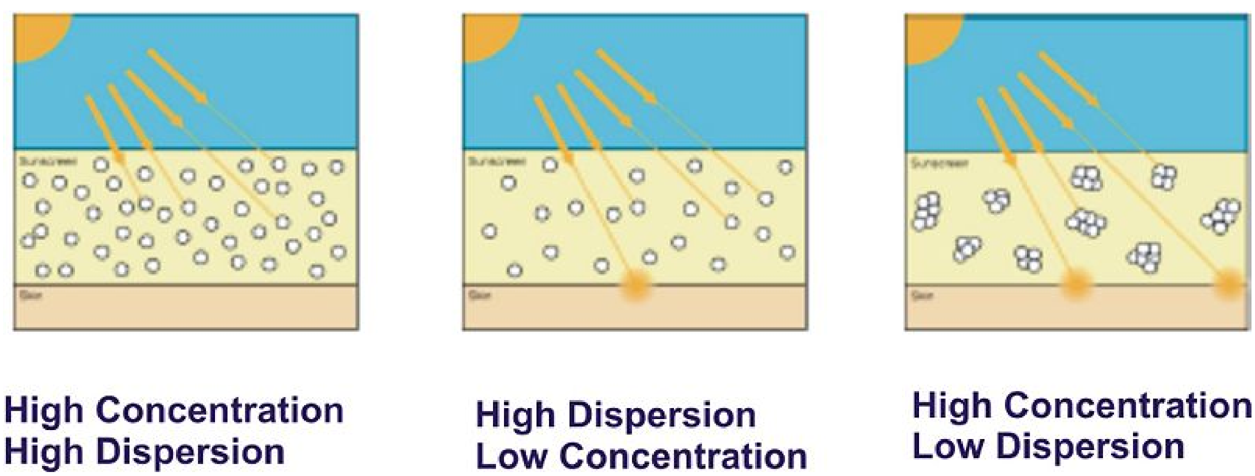


FIGURE 2.61

Slide 3: Prelude: Absorption of Light by Atoms

Absorption is the complementary process to emission. Instead of light being released by the atom, the atom captures the energy of light that shines on it.

In order for absorption to occur, the energy of the incoming photon must be exactly equal to the energy of an energy transition. This is the same principle that as for emission.

Since there are several possible electronic transitions, there are several energies of photons that can be absorbed. Each of these corresponds to a specific frequency of light $(E = hf)$. Each frequency of light in the visible spectrum appears as a specific color to ours eyes. This produces the visible absorption spectrum for helium shown in the slide.

Important Note: Even though only the visible absorption is shown here, molecules can also absorb other kinds of radiation.

Common Student Question: What happens to the light energy after it is absorbed?

Answer: Some time after light is absorbed, the electron will fall back down to a lower energy state. This releases the energy which is re-emitted as a photon or group of photons, often of lower energy. After this happens, the electron is free to absorb a new photon of light.

Slide 4: Prelude: Emission versus Absorption

Note that the absorption and emission spectra have lines at the same frequencies since the photons emitted and absorbed correspond to the same electronic transitions (same difference in energy levels). The characteristic difference in energy levels depend on the kind on atom and these spectra can be thought of as atomic "fingerprints."

Slide 5: If atomic absorption produces absorption lines, what do you think molecular absorption looks like? (Question Slide)

Have your students brainstorm ideas about how molecules are different from atoms and how this might relate to the absorption of light.

Slide 6: Organic Molecules: Energy Levels

Energy levels relate to the position and movement of electrons and nuclei with respect to each other. Since molecules have more than one nuclei (because they involve more than one atom), in addition to electronic energy levels, they can be in different rotational and vibrational modes based on the relative motion of the different nuclei. This creates multiple ground and excited energy levels for each electronic state.

Slide 7: Organic Molecules: Absorption

Since molecules have groups of energy levels, instead of only absorbing single frequencies of light, they absorb a set of closely spaced frequencies (and thus wavelengths). While this creates a curve and is referred to as an absorption range – it is really a set of discrete energy transitions that absorb similar frequencies of light.

Note that the absorption is the strongest in the middle of the range. This is because this is the wavelength that corresponds to the most common energy transition.

This is a good point in the presentation to give you students the Absorption Summary: Student Handout to refer to.

Slide 8: Organic Molecules: Absorption Curve

Note that molecule does not absorb evenly over its whole absorption range. The more peaked the absorption curve, the more quickly absorption drops off as you move away from the peak wavelength.

Student Check Question: What kind of UV light does the sunscreen molecule shown in the graph absorb?

Answer: Mostly UVB light. The UVB range is $\sim 280-320$ nm while the UVA range is $\sim 320-400$ nm . The absorption range runs from 255 nm to 345 nm and thus covers more of the UVB spectrum than the UVA one. In addition, from the peak at 310 nm the absorbance slope toward the shorter wavelengths is more gradual. You can demonstrate than there is more UVB than UVA being absorbed by drawing a vertical line at 320 nm and looking at the area under the curve on both sides (on the left you may want to draw a second cutoff line at 280 nm for the end of the UVB range). Students should notice that the area between the 280 and 320 nm lines (UVB region) is bigger than the area to the right of the 320 nm line (UVA region).

Slide 9: Organic Molecules: UV Protection

Different molecules have different peak absorption wavelengths, different ranges of absorption and differences in how quickly absorption drops off ("fat" curves as compared to "skinny" ones). It is important to realize that even within a molecule's absorption range, it does not absorb evenly and absorption at the ends of the range are usually low.

This is a good opportunity to refer back to the Summary of FDA Approved Sunscreen Ingredients: Student Handout which lists the absorption range for each FDA approved active ingredient.

Student Challenge Question: Which ingredients provide good UVA protection?

Answer: Avobenzone and Ecamsule are organic molecules that absorb in the UVA range. Zinc Oxide and Titanium Dioxide are inorganic compounds that absorb UVA light.

Student Challenge Question: The upper wavelength of absorption for Octocrylene and Zinc Oxide are both in the UVA range very similar. How can one provide little UVA protection and one provide good protection?

Answer: It has to do with the shape of the absorption curves. The absorption curve for inorganic compounds such as Zinc Oxide looks like a cliff, they absorb strongly up to the cutoff wavelength. The absorption curve for organic compounds is a peak, which means they absorb very weakly at the edge of their absorption range.

Slide 10: How do you think absorption by inorganic compounds might be different than absorption by molecules? (Question Slide)

Have your students brainstorm ideas about how the structure of inorganic compounds is different from that of molecules and how this might relate to the absorption of light.

Slide 11: Inorganic Compounds: Energy Levels

Energy levels relate to the position and movement of electrons and nuclei with respect to each other. Because of the large number of electrons and nuclei involved in the ionic clusters, there are many closely spaced possible energy states available in both the ground and excited states.

Slide 12: Inorganic Compounds: Absorption I

The difference in energy between ground states is so small that they are thought of as a continuous energy band. The same is true for the excited states. Within a band, very little energy is needed to change states.

This gap in energy between the ground states and the excited states, however, is comparatively large. This energy difference is called the band gap.

Slide 13: Inorganic Compounds: Absorption II

The band gap is basically an energy threshold. Light with any energy equal to or greater than the band gap energy can be absorbed because it will correspond to some transition between a ground state and an excited state.

The band gap energy tells us the smallest frequency of light that can be absorbed. All other transitions require more energy and thus will involve light with greater energy (and thus a higher frequency)

You may want to review the relationships between Energy and frequency $(E = hf)$ and between frequency and wavelength $(\lambda = c/f)$ with your students to help them understand the diagrams on this and the following slide.

Slide 14: Inorganic Compounds: Absorption Curve

These two graphs show the same absorption curve graphed first as a function of frequency and then as a function of wavelength. Remind students that frequency and wavelength are inversely related and a higher frequency corresponds to a smaller wavelength $(c = f * \lambda)$.

Student Discussion Question: What would the graph look like if it had transmittance (instead of absorbance) on the $y-$ axis?

Answer: The graph would be inverted; it would start low and then show a steep rise.

Slide 15: Inorganic Compounds: UV Protection

The energy of the band gap of ZnO corresponds to light of 380 nm meaning that it can absorb all light that has a wavelength of 380 nm or less. This includes almost the entire UVA range ($\sim 320-400$ nm) and does include the entire UVB ($\sim 280-320$ nm) range.

The energy of the band gap of TiO_2 corresponds to a wavelength of ~ 365 nm .

The absorption properties are based on chemical structure and thus are not affected by the size of the inorganic cluster. Both traditional inorganic ingredients and nano inorganic ingredients have the same absorption curve and absorb strongly across both the UVB and UVA range.

Slide 16: Absorption Summary

This slide summarizes the three kinds of absorption introduced in this PowerPoint and replicates two of the rows of the Absorption Summary: Student Handout. The key concept to review with students is how the different structure of atoms, organic molecules and inorganic compounds leads to differences in energy level spacing which in turn leads to the difference absorption spectrum.

Slide 17: Can sunscreens absorb all of the UV light that shines on our skin? (Question Slide)

This slide transitions to the idea that many molecules (or inorganic clusters) are needed to protect our skin. Ask your students why they think applying a thin layer of sunscreen lowers its effectiveness.

Slide 18: Answer: It Depends I

In order for a molecule (or inorganic cluster) to absorb UV light, the UV light must come into contact with it. Sunscreens are colloidal suspensions which means that the active (absorbing) ingredients are embedded in a (non-absorbing) lotion.

The greater the amount of sunscreen applied, the greater the chance that UV light will come into contact with an active ingredient, and thus get absorbed.

Because the light absorbing clusters are suspended in another medium, a single layer application does not provide total protection. Imagine a clear sheet of plastic with some black dots on it. If you shine a light above it, you will see a shadow of the dots because only these specific areas block the light. If you put a second sheet with a different pattern of dots on it on top of the first and shone a light, you would start to see bigger patches of shadow. If you continue to do this with more and more sheets, eventually you will see a rectangular shadow as the full area of the plastic is blocked. The absorbing clusters suspended in the sunscreen work the same way, if you apply too thin a layer, it is like only having a few sheets of plastic.

Layer Demonstration: You may want to do an in-class demo of the concept described above by printing black dots onto sheets of acetate and having the class try predict how many sheets are required to get "total protection". The actual number will vary with the size of the dots you make, but it is generally many more than student expect.

Slide 19: Answer: It Depends II

In addition to the amount of sunscreen, there are two factors that sunscreen companies work with to make sunscreens as effective as possible. The first is the concentration of the active ingredients. The more active ingredient molecules or inorganic clusters you have, the greater the chance that light will come into contact with them.

Student Challenge Question: If a higher concentration of active ingredients makes sunscreens more effective, why are the concentrations listed on the bottle so low? (You may want to ask students if they remember the concentrations they saw in the sunscreen label activity)

Answer: Too much of any chemical can be harmful to the skin. When the FDA approves a sunscreen ingredient, they also give the maximum concentration that can be used. In addition, if too much of an ingredient is present, it can be hard to keep it dispersed.

Dispersion is a measure of how evenly distributed the active ingredients are throughout the sunscreen. If they are evenly spaced, this is good dispersion and leads to effective UV absorption. If the active ingredients clump together, it is easier for UV light to pass through the sunscreen without getting absorbed, and thus cause damage to our skin.

Slide 20: Summary

Key take-away points from this presentation are:

- Chemical structure determines energy level spacing, which in turn determines what wavelength(s) of light are absorbed.
- Organic sunscreen ingredients exist as discrete molecules and thus are good at absorbing narrow ranges of UV light.
- Inorganic sunscreen ingredients exist as ionic clusters and thus are good at absorbing the whole UV range (below the band gap wavelength)

Reflecting on the Guiding Questions: Teacher Instructions #38; Answer Key

You may want to have your students keep these in a folder to use at the end of the unit, or collect them to see how your students' thinking is progressing. You can also have a group discussion about what students learned from the activity that helps them answer the guiding questions.

Discussion Idea:

For each "What I still want to know" section, have students share their ideas and discuss whether their questions are scientific ones or questions of another sort. Scientific questions are questions about how the natural world operates that can be answered through empirical experiments. Other kinds of questions might be ethical in nature (e.g. do friends have a responsibility to persuade friends to use sunscreen?) or policy questions (e.g. should the FDA endorse the most effective sunscreens?).

Think about the activities you just completed. What did you learn that will help you answer the guiding questions? Jot down your notes in the spaces below.

1. What are the most important factors to consider in choosing a sunscreen?

What I learned in this activity:

Possible Answers:

Since inorganic ingredients absorb both UVA and UVB, sunscreens that include them have broadband protection

Organic ingredients each absorb a specific wavelength range that can be in the UVA or UVB range. To ensure broadband protection, it is important to choose a sunscreen that has a combination of ingredients that will absorb both kinds of light. Avobenzone and Ecamsule are the two FDA approved organic ingredients that absorb strongly across the UVA range.

Regardless of the ingredients, it is important to make sure that we use enough of the sunscreen we choose for it to be effective.

What I still want to know:

2. How do you know if a sunscreen has "nano" ingredients?

What I learned in this activity:

Possible Answers:

"Nano" ingredients are smaller versions of traditional inorganic ingredients. If a sunscreen contains Zinc Oxide or Titanium Dioxide, they may be in nanoparticle form.

What I still want to know:

3. How do "nano" sunscreen ingredients differ from most other ingredients currently used in sunscreens?

What I learned in this activity:

Possible Answers:

"Nano" ingredients are smaller versions of traditional inorganic ingredients which exist as ionic clusters. They are different from most ingredients currently used in sunscreens which are organic molecules.

While organic molecules absorb narrow bands of the UVA or UVB spectrum, all inorganic ingredients (including "nano" ingredients) absorb strongly in both the UVA and UVB range up to their cutoff wavelength: 380 nm (ZnO) or 365 nm (TiO_2) .

What I still want to know:

How Sunscreens Appear: Interactions with Visible Light

Teacher Lesson Plan

Contents

- How Sunscreens Appear: Interactions with Visible Light: Teacher Lesson Plan
- How Sunscreens Appear: Interactions with Visible Light: PowerPoint Slides and Teacher Notes
- Ad Campaign Project (ChemSense Activity): Teacher Instructions #38; Grading Rubric
- Sunscreens #38; Sunlight Animations: Teacher Instructions #38; Answer Key
- Reflecting on the Guiding Questions: Teacher Instructions #38; Answer Key

Orientation

This lesson provides an examination of how visible light interacts with matter to produce the appearance of color. There are several demonstrations embedded in the PowerPoint presentation that you can do with your class.

There is a choice of activities in this lesson. Both possible activities center around animations illustrating the interaction between visible light and sunscreen particles or skin, but one activity has students generate animations while the other provides them for the students to analyze. The animation creation activity is a more robust project that pushes students to really probe the underlying mechanism, but if time constraints are an issue, the pre-made animations discussion engages students in many of the same issues.

- The Ad Campaign Project is a ChemSense Activity that puts students in the position of designing an animation that shows consumers how different sized particle interact with visible light. Students use the dedicated ChemSense Animator to aid them in this task. This project takes two days, plus an extra day if students have not used the program before.
- The Sunscreens #38; Sunlight Animations Activity uses a pre-made flash animation (available from http://nanosense.org/act and probing questions to let students explore many of the design issues they would have encountered had they created their own animation.
- The How Sunscreens Appear: Interactions with Visible Light PowerPoint focuses on the details of how matter scatters light and the phenomenon of color.
- The Scattering of Light by Suspended Clusters: Student Reading provides more details about this kind of interaction between light and matter.
- The Reflecting on the Guiding Questions Worksheet asks students to connect their learning from the activities in the lesson to the overall driving questions of the unit.

Essential Questions (EQ)

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

1. What are the most important factors to consider in choosing a sunscreen?
2. How do you know if a sunscreen has “nano” ingredients?
3. How do “nano” sunscreen ingredients differ from most other ingredients currently used in sunscreens?

Enduring Understandings (EU)

Students will understand:

(*Numbers correspond to learning goals overview document*)

1. How the energies of different wavelengths of light interact differently with different kinds of matter.

2. Why particle size can affect the optical properties of a material.

6. How to apply their scientific knowledge to be an informed consumer of chemical products.

Key Knowledge and Skills (KKS)

Students will be able to:

(*Numbers correspond to learning goals overview document*)

1. Describe the mechanisms of absorption and scattering by which light interacts with matter.
2. Describe how particle size, concentration and thickness of application affect how particles in a suspension scatter light.
3. Explain how the phenomenon of seeing things in the world is a human visual response depending on how light interacts with objects.

TABLE 2.29: Sunscreen Appearance Timeline (with Ad Campaign Activity)

Day	Activity	Time	Materials
	Homework: Scattering of Light by Suspended Clusters: Student Reading	20 min	Copies of Scattering of Light by Suspended Clusters: Student Reading
Day 1 (50 min)	Show How Sunscreens Appear: Interactions with Visible Light PowerPoint Slides, using the embedded question slides and teacher’s notes to start class discussion. Perform Demonstrations associated with PowerPoint Presentation (optional)	30 min	How Sunscreens Appear: Interactions with Visible Light Slides & Teacher Notes Computer and projector Optional Demonstration Materials: Blank sheet of acetate, Black Marker, flashlights, colored gels for flashlights, water, milk.

TABLE 2.29: (continued)

Day	Activity	Time	Materials
	Hand out copies of the Ad Campaign Project (ChemSense Activity): Student Instructions	20 min	Photocopies of Ad Campaign Project (ChemSense Activity): Student Instructions
	Talk with students about the goal of the activity, the audience they will be preparing the animation for and the criteria they will be judged on.		Computer with ChemSense installed for each student team (2 – 3 students)
	Have students start to work in teams of 2 or 3 to create the animations.		
	Circulate throughout the classroom to help students.		
Day 2 (50 min)	Students continue to work on their animations. Towards the second half of the class, encourage students to finish up their animations and start to think about how they will present the animations to the class.	50 min	
	Homework: Prepare for Presentation of Animation to class	30 min	
Day 3 (50 min)	Class presentation and discussion of animations using discussion questions in Ad Campaign Project (ChemSense Activity): Teacher Instructions & Grading Rubric.	35 min	
	Have students work individually or in small groups to fill out the Reflecting on the Guiding Questions: Student Worksheet.	5 min	Copies of Reflecting on the Guiding Questions: Student Worksheet

TABLE 2.29: (continued)

Day	Activity	Time	Materials
	Bring the class together to have students share their reflections with the class. This is also a good opportunity for you to address any misconceptions or incorrect assumptions from students that you have identified in the unit up until now.	10 min	Reflecting on the Guiding Questions: Teacher Instructions & Answer Key

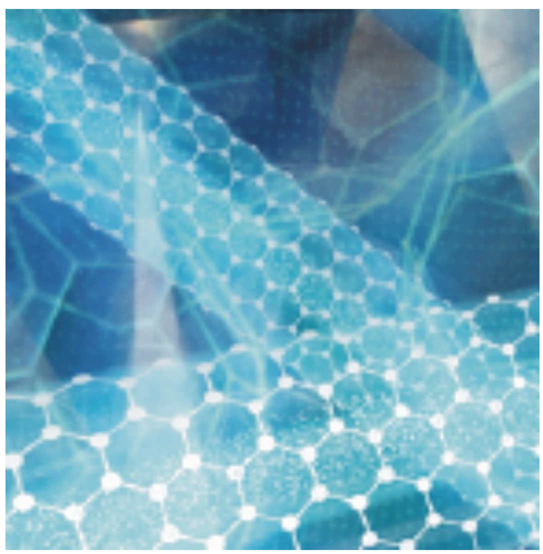
TABLE 2.30: Sunscreen Appearance Timeline (with Pre-made Animation Activity)

Day	Act	Time	Materials
	Homework: Scattering of Light by Suspended Clusters: Student Reading	20 min	Scattering of Light by Suspended Clusters: Student Reading
Day 1 (50 min)	Show How Sunscreens Appear: Interactions with Visible Light PowerPoint Slides, using the embedded question slides and teacher's notes to start class discussion. Perform Demonstrations associated with PowerPoint Presentation (optional)	30 min	How Sunscreens Appear: Interactions with Visible Light PowerPoint Slides & Teacher Notes Computer and projector Optional Demonstration Materials: Blank sheet of acetate, Black Marker, flashlights, colored gels for flashlights, prism, pencil, beakers, water, milk, acrylic block, laser.
	Hand out copies of the Sunscreens & Sunlight Animations: Student Instructions & Worksheet. Have students work in teams of 2 or 3 to view the animations and answer the questions on the worksheet. If few computers are available, use a single computer and projector to make it a whole class activity.	20 min	Copies Sunscreens & Sunlight Animations: Student Instructions & Worksheet Computers with for each student team or one computer and projector for the class
Day 2 (30 min)	Whole class discussion of what makes large particle sunscreens appear white.	15 min	

TABLE 2.30: (continued)

Day	Act	Time	Materials
	Have students work individually or in small groups to fill out the Reflecting on the Guiding Questions: Student Worksheet.	5 min	Copies of Reflecting on the Guiding Questions: Student Worksheet
	Bring the class together to have students share their reflections with the class. This is also a good opportunity for you to address any misconceptions or incorrect assumptions from students that you have identified in the unit up until now.	10 min	Reflecting on the Guiding Questions: Teacher Instructions & Answer Key

How Sunscreens Appear:



Interactions with Visible Light

The Problem With Traditional Inorganic Ingredients

- Sunscreens with traditional size ZnO and TiO_2 clusters appear white on skin
  - People often don't want to use them
  - They may also use them but apply less than the recommended amount
  - This reduces blocking ability and can lead to burns

What makes sunscreens with traditional size inorganic clusters appear white?

And. . .

. . . what makes our skin appear "skin-colored" in the first place?

Remember the Electromagnetic Spectrum?

FIGURE 2.62

FIGURE 2.63

FIGURE 2.64

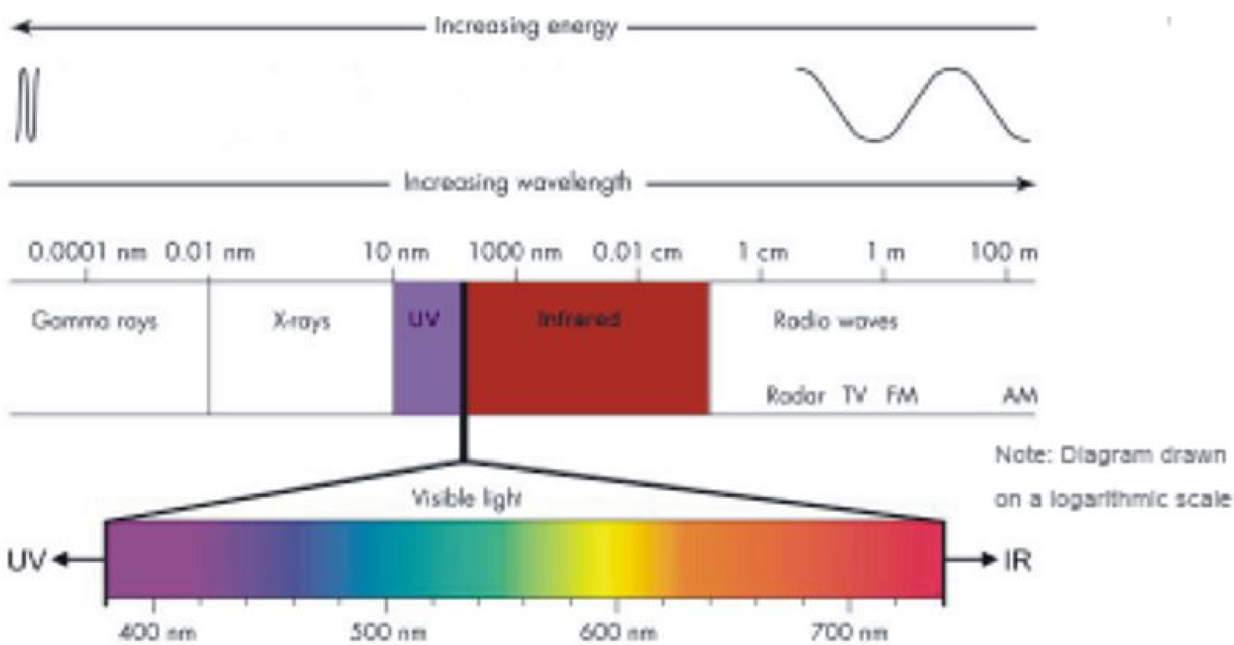


FIGURE 2.65

- Different colors of light have different wavelengths and different energies

Reflected Light Gives an Object its Color

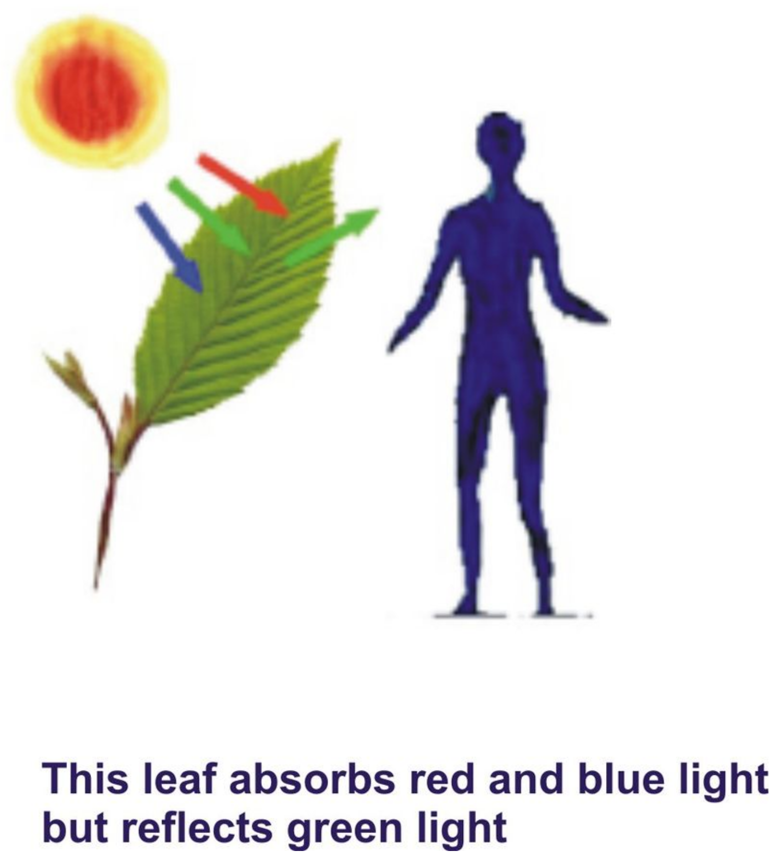


FIGURE 2.66

- Visible light shining on an object is either absorbed or reflected
  - Only reflected wavelengths reach our eyes
  - This makes object appear a certain color
- Color is a function of the interaction between the light and the object
  - It's not quite right to say an object *is* a certain color – it depends on the light too!

What determines which colors (wavelengths) of visible light are absorbed?

The Leaf Molecules' Energy Levels Determine Absorption

- Only light with the right amount of energy to excite electrons is absorbed
- Same process as seen for UV light absorption
  - Different kinds of molecules and inorganic compounds absorb different wavelengths of light

Chlorophyll's Visible Absorption Spectrum

- Chlorophyll is a molecule found in many plants
  - It absorbs light to excite its electrons which are then used in photosynthesis

FIGURE 2.67

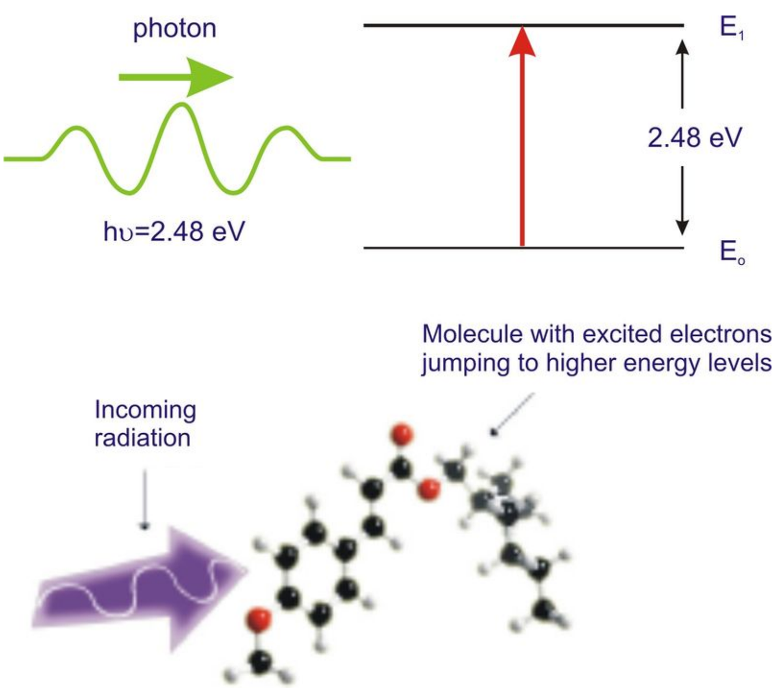


FIGURE 2.68

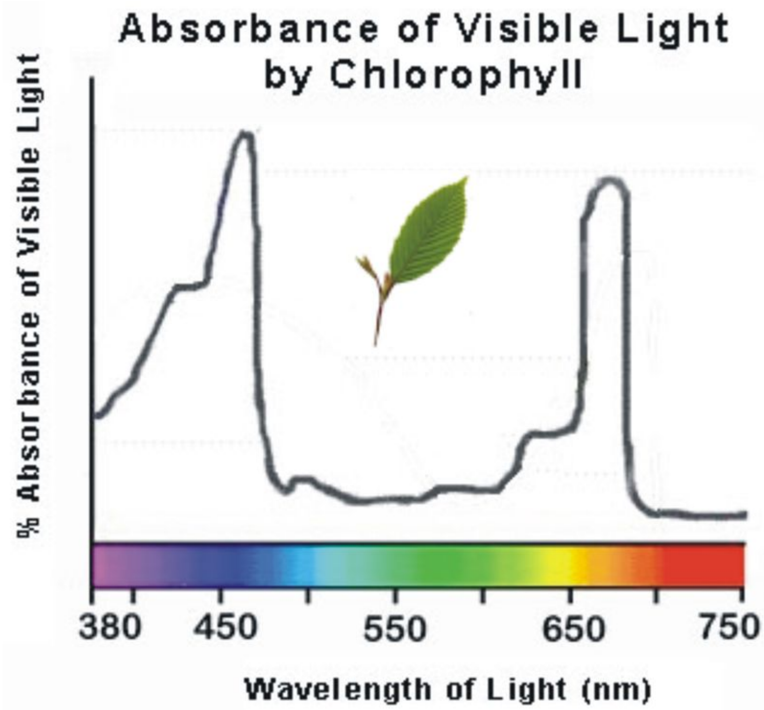


FIGURE 2.69

- It absorbs most visible light except for green light
  - This is why grass (and leaves and bushes) are green

So what makes our skin appear "skin-colored"?

FIGURE 2.70

Pigments in our Skin Give it "Color"

FIGURE 2.71

- Pigment:
  - Molecule that absorbs certain kinds of visible light and thus appears a certain color
- Human skin color determined by melanin
  - A group of pigment molecules
  - Each kind has a unique visible absorption spectrum
  - People can also have more or less of different kinds of melanin

What Do Melanin Molecules Do?

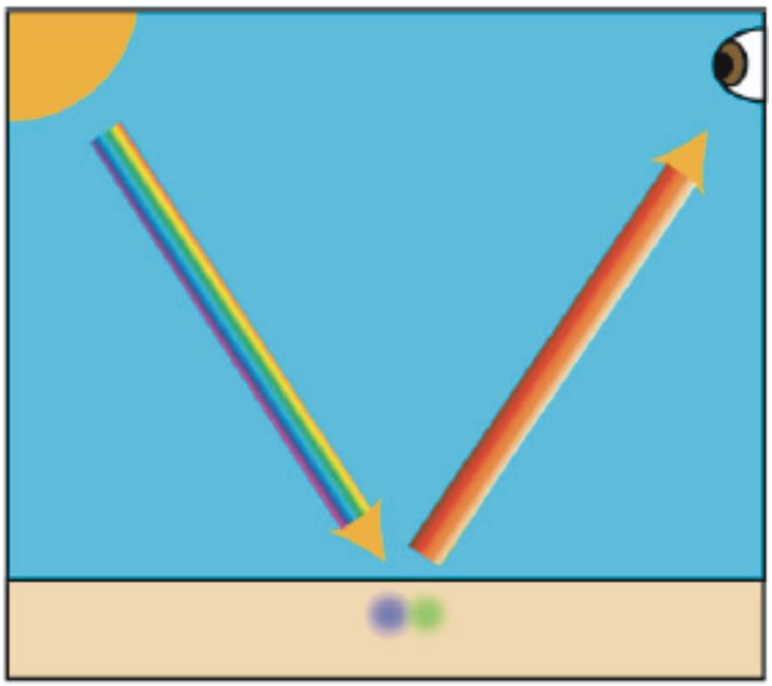


FIGURE 2.72

- Each kind of melanin absorbs specific wavelengths in the visible spectrum
  - Blue/green wavelengths subtracted from the light
- Our skin appears the color of wavelengths that are left
  - Red/brown/yellow rays reflected to our eyes

So what makes sunscreens with traditional inorganic clusters appear white?

Inorganic Clusters Can Scatter Visible Light

- When light encounters a cluster of atoms or ions suspended in another medium, it can be sent off in multiple directions
- The energy from the light is redirected without a chemical interaction with the atoms
  - This is different than absorption because no energy transformation occurs

Multiple Scattering

- After light is redirected once, it may encounter another cluster and be redirected again

FIGURE 2.73

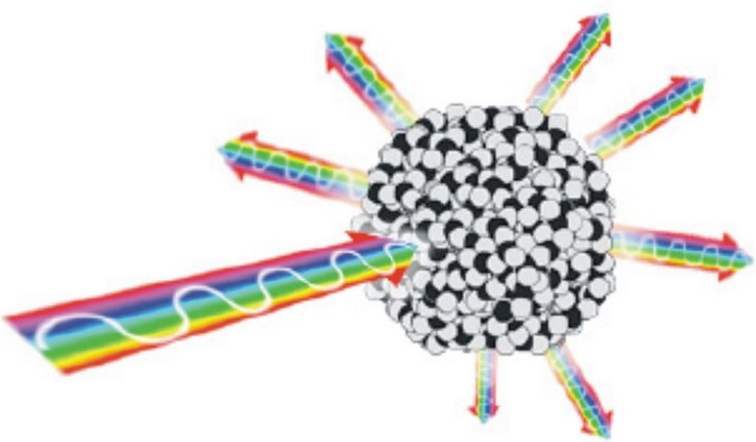


FIGURE 2.74

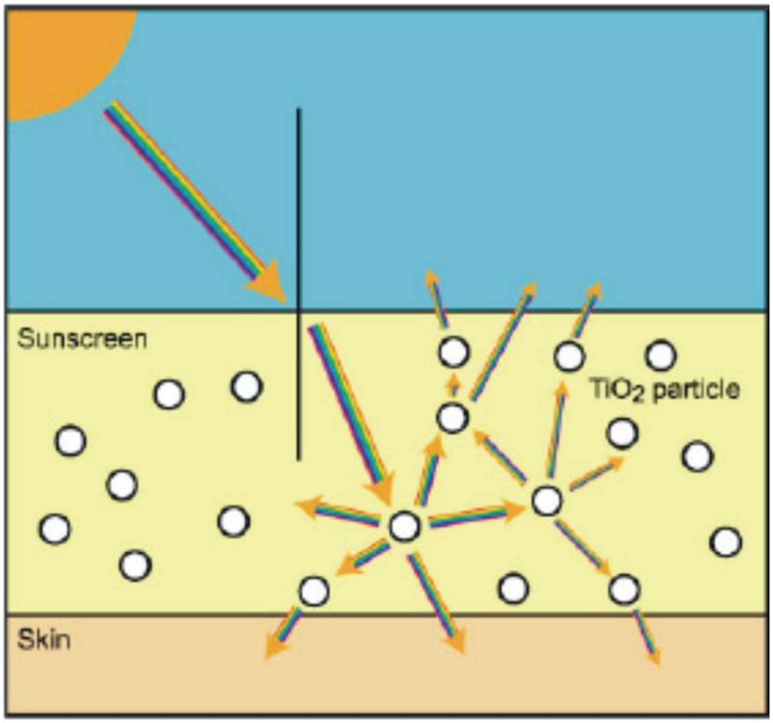


FIGURE 2.75

- When this happens many times, it is called multiple scattering

Front and Back Scattering

Light eventually goes in one of two directions:

- Back the way it came (back scattering)
  - Back-scattered light is reflected
- Forwards in the same general direction it was moving (front scattering)
  - Front-scattered light is transmitted

Scattering by Traditional ZnO and TiO_2

- Maximum scattering occurs for wavelengths twice as large as the cluster
  - Traditional ZnO and TiO_2 have a diameter $>$ 200 nm
  - Scatter light with a λ near 400 nm - this includes visible light!

Back Scattered Light Makes the Sunscreen Look White

- The back scattered light contains all colors in the visible spectrum
- When this light reaches our eyes, the sunscreen appears white

What do you think might be different about how nano sunscreen ingredients interact with visible light?

Nanosized Inorganic Clusters

- Maximum scattering occurs for wavelengths twice as large as the clusters

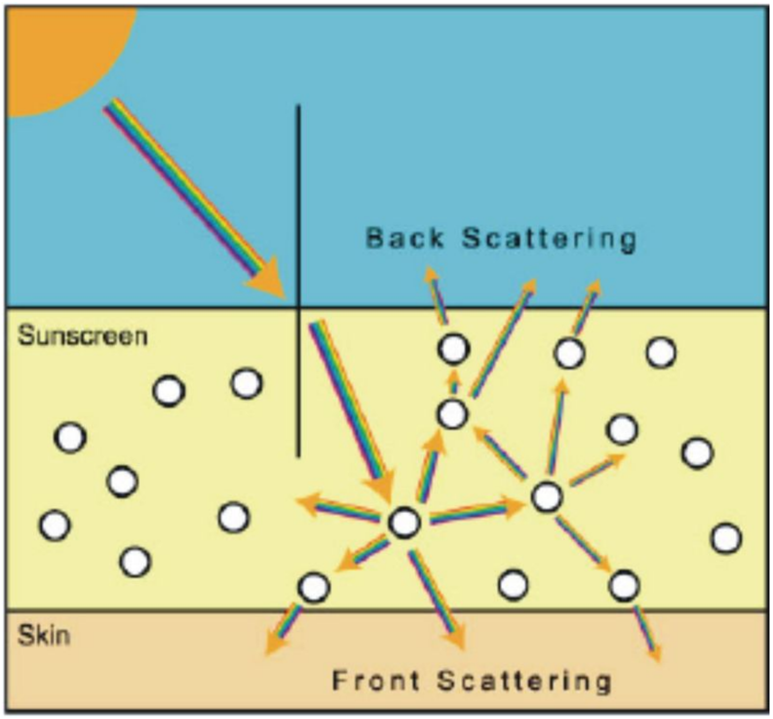


FIGURE 2.76

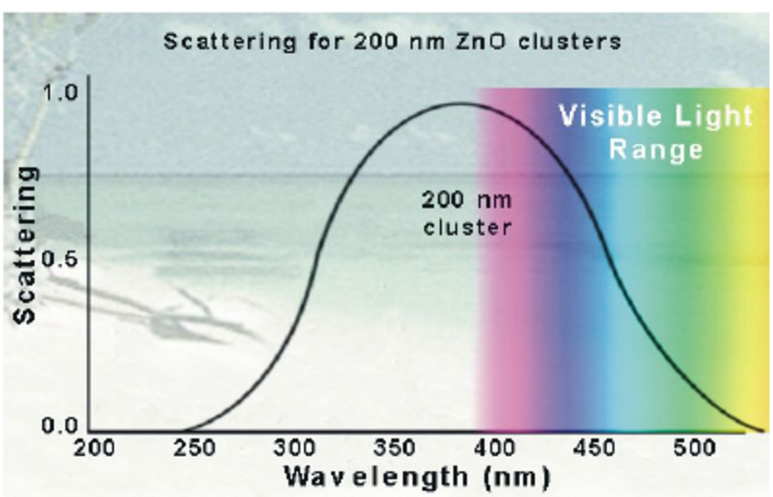


FIGURE 2.77

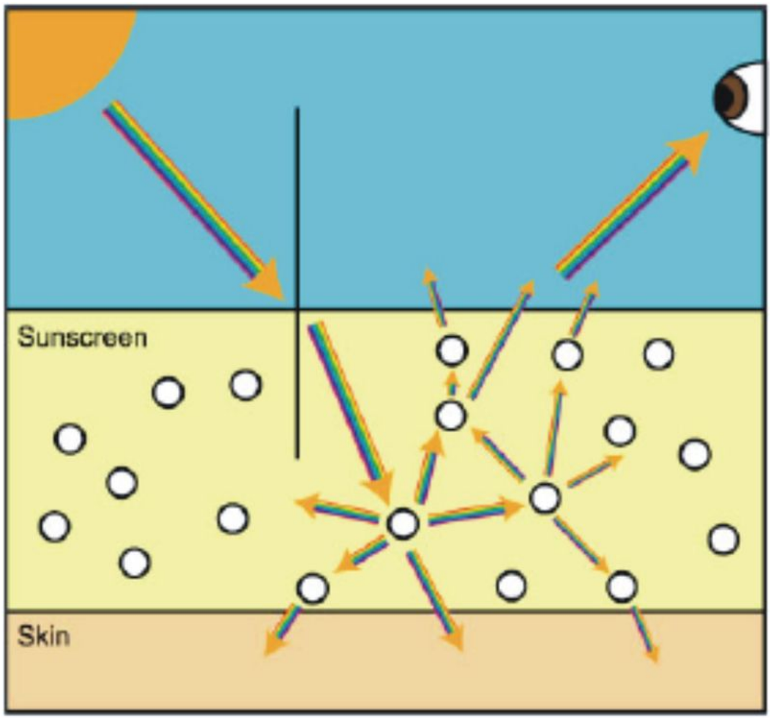


FIGURE 2.78

FIGURE 2.79

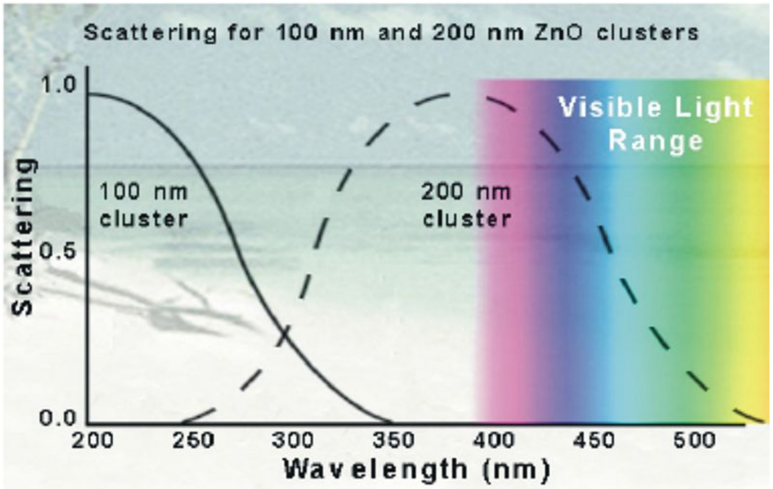


FIGURE 2.80

– Make the clusters smaller (100 nm or less) and they won't scatter as much visible light

Nano ZnO **and** TiO_2

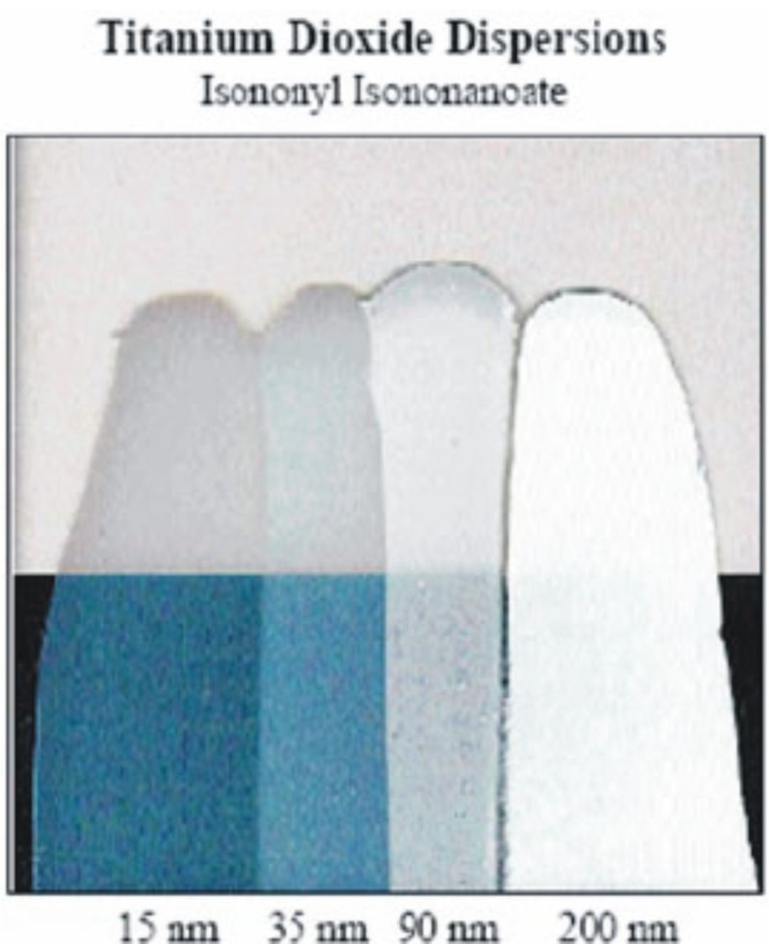


FIGURE 2.81

- As the cluster size gets smaller and smaller, less and less visible light is scattered
- This makes the sunscreen more and more transparent

"Clear" Sunscreen

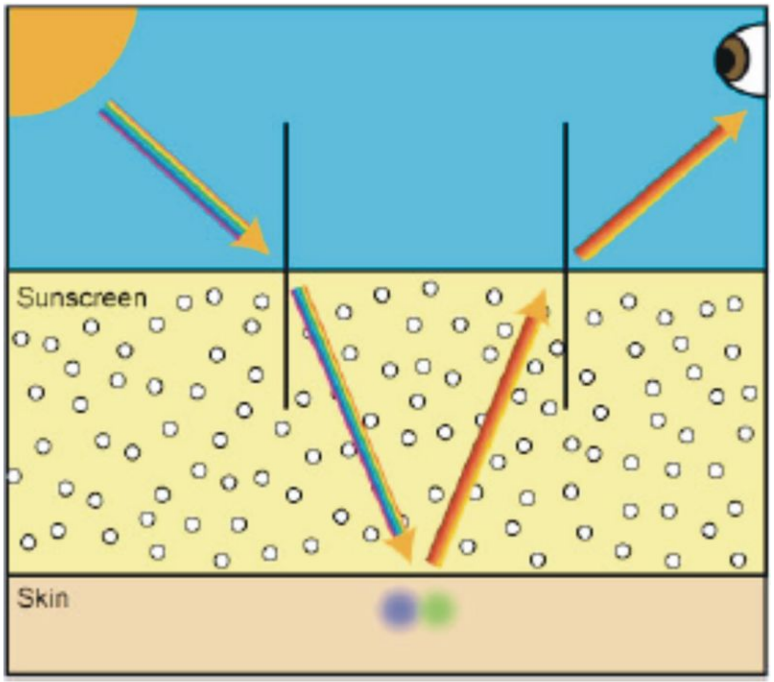


FIGURE 2.82

- Light passes through the sunscreen to the skin
  - Minimal scattering
- Melanin can absorb the blue-green wavelengths
  - Red-yellow ones are still reflected
- The skin appears the same as it would without the sunscreen
  - Sunscreen is "clear"

Summary

- Our skin appears "skin colored" because melanin absorbs the blue-green light from the sun
- Large inorganic sunscreen clusters scatter all visible light back towards our eyes, creating a white appearance
- Nano inorganic sunscreen clusters are too small to scatter visible light, so the light reaches our skin, the melanin can absorb the blue-green light, and our skin appears skin colored

Teacher Notes

Overview

This series of slides deals with the interaction of sunscreens and visible light. (This is important to highlight repeatedly during this lesson as students tend to get confused with the UV light interaction they have already studied.) The slides begin with a brief introduction to the concept of color and its relationship to light as an electromagnetic wave. This foundation is then used to explain why our skin has the color it does and how large inorganic sunscreen ingredients interact with light to produce a white appearance. Finally the slides discuss nanoparticles and why they appear clear.

There are several demonstrations embedded in this slide set that you may want to prepare ahead of time.

For further background on light and color as well as additional classroom demonstrations, you may want to obtain the book "Light: Stop Faking It!" available for order online at http://store.nsta.org/showItem.asp?product=PB169X3.

Slide 1: Title Slide

Slide 2: The Problem with Traditional Inorganic Ingredients

Student Discussion Question: Why does the amount (thickness) of sunscreen applied matter in terms of ability to protect our skin?

Answer: Because the light absorbing clusters are suspended in another medium, a single layer application does not provide total protection. Imagine a clear sheet of plastic with some black dots on it. If you shine a light above it, you will see a shadow of the dots because only these specific areas block the light. If you put a second sheet with a different pattern of dots on it on top of the first and shone a light, you would start to see bigger patches of shadow. If you continue to do this with more and more sheets, eventually you will see a rectangular shadow as the full area of the plastic is blocked. The absorbing clusters suspended in the sunscreen work the same way, if you apply too thin a layer, it is like only having a few sheets of plastic.

Layer Demonstration: You may want to do an in-class demo of the concept described above by printing black dots onto sheets of acetate and having the class try predict how many sheets are required to get "total protection". The actual number will vary with the size of the dots you make, but it is generally many more than student expect.

Slide 3: What makes sunscreens with traditional size inorganic clusters appear white? (Question Slide)

Have your students brainstorm ideas about why sunscreens with traditional inorganic clusters might appear white. If your students don't bring it up on their own, prompt them to consider the mechanisms by which light interacts with matter (Reflection, Transmission #38; Absorption $R+T+A=1$)

Slide 4: What makes our skin appear "skin-colored" in the first place? (Question Slide)

Have your students brainstorm ideas about what gives skin its color. Is it is the skin matter itself? Is it the light from the sun? Is it the interaction between them? Ask them how they could gather evidence to support their view.

Slide 5: Remember the Electromagnetic Spectrum?

Discussion Question: Does visible light have more or less energy than UV light? How do you know?

Answer: Less because it has longer wavelengths (smaller frequencies) and $E=hf$. We also know that visible light isn't as dangerous as UV light because it has less energy.

Discussion Question: What kind of visible light has the most energy? What kind has the least? What kind falls in the middle?

Answer: Blue/violet light has the most energy because it has the smallest wavelength (greatest frequency) of the visible spectrum $(\sim 400-500 \text{ nm})$. Red light has the least energy because it has the greatest wavelength (smallest frequency) of the visible spectrum $(\sim 700-750 \text{ nm})$. Yellow/Green light falls in the middle with a wavelength of $\sim 550-600$ nm). One way to help students to remember this is with the acronym often used in art classes of "Roy G. Biv" (Red Orange Yellow Green Blue Indigo Violet) that lists the colors in order of increasing energy.

Slide 6: Reflected Light Gives an Object its Color

Color Demonstration: To do this demonstration you will need to make one or more colored flashlights by placing a color filter in front of a flashlight. Filters are available from Educational Innovations (http://www.teachersource.com/) at $\sim$ \$12 for a full set (Item FIL-100) or you may be able to borrow some from your school's physics teacher. A quick and inexpensive option is to use the red and blue lenses from an old pair of "3D" glasses.

Demo #1: Shine a white flashlight on a green apple in a dark room – the apple appears green because all light (red, orange, blue) except for the green light is absorbed. Shine a red light on the apple and it will appear a dark grey because there is no green light to reflect and all the light is absorbed. You can do similar demos with any color light and oppositely colored object. This shows that when no color is reflected, object appear black (black is the absence of color).

Demo#2: Shine a red flashlight on a white piece of paper in a dark room – that part of the paper will appear red. Add a blue flashlight and a yellow one on top of the red one. The paper should look white again because all three parts of spectrum are being reflected. This shows that the appearance of white is the combination of all colors. (Similarly, a prism can be used to separate the different parts of white light back into a rainbow).

Slide 7: What determines which colors (wavelengths) of visible light are absorbed? (Question Slide)

Have your students brainstorm ideas about what might determine which colors (wavelengths) of visible light are absorbed by different object. If your students don't bring it up on their own, prompt them to remember what determined the kinds of UV light each kind of sunscreen ingredient absorbs – it is the energy levels in the absorbing substance.

Slide 8: The Leaf Molecules' Energy Levels Determine Absorption

It is important to highlight the difference between what happens to the UV light and what happens to the visible light. Even though both may be absorbed, absorption of UV light causes skin damage while absorption of visible light doesn't.

Discussion Question: Are the energy level spacings for molecules that absorb visible light greater or smaller than in molecules that absorb UV light?

Answer: The specific electron transitions caused by the absorption of visible light require less energy than UV transitions because visible light has less energy than UV.

Slide 9: Chlorophyll's Visible Absorption Spectrum

Student Challenge Question: What would the reflection graph for chlorophyll look like?

Answer: It would be the inverse of the graph shown here, very high from $\sim 460 - 650$ nm with a sharp drop off at either side.

Biology Connection: The light energy absorbed by the chlorophyll is used in photosynthesis to make ATP. The absorption causes an electron to "jump" into a higher energy state which starts the electron transport chain.

The electron transport chain is a series of rapid transfers between protein complexes and simple organic molecules (oxidation-reduction reactions) found in the membrane systems of the chloroplast. This series of reactions produces energy rich molecules such as ATP.

Slide 10: So what makes our skin appear "skin-colored"? (Question Slide)

Have your students brainstorm ideas about what makes our skin appear "skin-colored". If they generate the idea that there is something in our skin that absorbs selectively in the visible spectrum, push them to think about whether it is the kind of these molecules or the quantity of them that accounts for different skin colors.

Slide 11: Pigments in our Skin Give it "Color"

It is not just the amount of melanin, but the kinds of melanin that determine our skin color. The amount and kinds of melanin in a person's skin is an inherited trait.

Slide 12: What Do Melanin Molecules Do?

Different melanin molecules absorb different wavelengths of light based on the differences in the spacing of their energy levels. If you have covered Lesson 3 with your students, you can point out that melanin is an organic molecule and thus absorbs a small range of frequencies, similar to these molecules. The difference is that the spacing between the energy levels in melanin is smaller than for organic sunscreen molecules. Thus it absorbs visible light, which has less energy than UV light.

Slide 13: So what makes sunscreens with traditional inorganic clusters appear white? (Question Slide)

Have your students brainstorm ideas about what makes sunscreens with traditional inorganic clusters appear white.

Possible Student Misconception #1: Students make think that sunscreen clusters absorb all colors of visible light, but if this were true, then the sunscreen would appear black. If students come up with this idea, you may want to review the demos in slide 6 with them.

Possible Student Misconception #2: Students make think that sunscreen clusters reflect all colors of visible light. This is true on a macro-level, but the micro-level mechanism is different because reflection is a phenomenon solid objects and sunscreens are colloidal suspensions, thus the "reflection" is due to scattering.

Slide 14: Inorganic Clusters Can Scatter Visible Light

Scattering is a physical process that depends on cluster size, the index of refraction of the cluster substance and the index of refraction of the suspension medium. No energy transformations occur during scattering (like they do in absorption), energy is simply redirected in multiple directions. The wavelengths (and energy) of light coming in and going out are always the same.

Important Differences between Absorption #38; Scattering:

Absorption is a process that involves an energy transformation. What light can be absorbed is determined by a chemical's energy levels, which is determined by its chemical identity and structure. The size of the molecule or cluster is not important.

Scattering is a physical process that does not involve an energy transformation. What light can be scattered is determined primarily by the size of suspended cluster, not its identity.

Slide 15: Multiple Scattering

Light scattering is a common phenomenon that many of your students will have experienced (though they may not realize that it…). Scattering is what allows us to "see" light go past us, because the clusters scatter the light as it passes. For example when you are in a dusty room on a sunny day the dust scatters the light and you "see" the scattered light. You can show this to students by clapping blackboard erasers (or shaking out any other kind of dust) near a window on a sunny day. If it isn't sunny, you can do the following demonstration:

Scattering Demonstration

Prepare two beakers: one with 100 mL of water and one with 95 mL of water and 5 mL of milk. Place the beakers on a dark tabletop and turn off the lights. Shine a thin flashlight or laser pointer through the side of the water container and have students look at the sides of the container. Then do the same for the beaker with the milk in it.

For the water beaker: You shouldn't see anything since there are no clusters to scatter the light.

For the milk and water beaker: You should be able to see the beam in the liquid since the proteins and other very small clusters in the milk are suspended in the water and scatter the light. To verify that light is scattered in all directions you can have your students try different observation points (looking down on the beaker, looking at the beaker from an oblique angle).

Slide 16: Front and Back Scattering

Multiple scattering is a phenomenon of colloids (suspended clusters). When light is scattered, at the micro level it goes in many directions. At the macro level, it eventually either goes back the way it came or forwards in the same general direction it was moving. These are known as back- and front- scattering and they contribute to reflection and transmission respectively.

Note that the formula presented earlier (Reflection + Transmission + Absorption = 100%) still holds. Scattering simply contributes to the "reflection" and "transmission" parts of the equation. Light that has been absorbed cannot be scattered.

Slide 17: Scattering by Traditional Nano ZnO and TiO_2

Maximum scattering occurs when the wavelength is twice as large as the cluster size. Since traditional inorganic sunscreen ingredients have diameter > 200 nm , they scatter light which is near 400 nm in diameter – this includes light in the visible spectrum.

Slide 18: Back Scattered Light Makes the Sunscreen Look White

The scattering of visible light by ZnO and TiO_2 is the cause of the thick white color seen in older sunscreens. When the different colors of visible light are scattered up and away by the sunscreen, they reach our eyes. Since the combination of the visible spectrum appears white to our eyes, the sunscreen appears white.

If you are not planning on doing the animation activities with your class, you may want to demo the animations at this point. The animations are available at http://nanosense.org/activities/clearsunscreen/index.html and are explained in the Sunscreens #38; Sunlight Animations: Teacher Instructions #38; Answer Key in this lesson.

Slide 19: What do you think might be different about how sunscreen ingredients interact with visible light? (Question Slide)

Have your students brainstorm ideas about what how nano sunscreen ingredients are different from traditional inorganic sunscreens ingredients (they are much smaller) and how this might influence the way they interact with visible light (their size is much smaller than half the wavelength of visible light, thus they are not good scatterers for this kind of light).

Slide 20: Nanosized Inorganic Clusters

Note that changing the cluster size simply shifts the scattering curve to a lower wavelength. While this may or may not change the amount of overall scattering, it reduces the amount of scattering in the visible range, which is what is important in determine appearance.

Slide 21: Nano ZnO and TiO_2

Advanced Content: In addition to the problem of manufacturing nanoparticles of ZnO and TiO_2 , there is an additional problem in keeping the clusters dispersed since the clusters often tend to clump together. This creates two problems: one, when clusters clump, the absorption of UV light can be spotty; and two, the effective cluster size becomes larger and the clusters are more likely to scatter visible light and appear white.

You may want to talk with your students about the difference between primary cluster size and the dispersion cluster size. The difference is that even if you produce clusters of 15 nm , very often some of these will clump together in the sunscreen to form effectively larger clusters (called dispersion clusters). This is one reason that sunscreen manufacturers are so concerned with both the medium and the procedure for dispersing the clusters in the sunscreen formulation.

For example, in the graphic shown for the 15 nm clusters the dispersion cluster size is 125 nm and for the 35 nm clusters it is 154 nm .

Slide 22: "Clear" Sunscreen

When visible light is not scattered by the clusters, it passes through the sunscreen and is reflected by our skin (blue and green rays are absorbed by pigments in the skin and the red, yellow and orange rays are reflected to our eyes giving skin its characteristic color).

Student Discussion Question: Does changing the cluster size change the UV blocking ability?

Answer: No, decreasing the cluster size will not affect its ability to block the UV rays, because absorption is a chemical process and determined by the energy levels of the matter (which do not change dramatically with size). Thus the nano-sized clusters are still good UV blockers.

Student Challenge Question: Why was the scattering issue never a problem for organic ingredients?

Answer: Organic sunscreen molecules are smaller than 10 nm (usually 1 – 20 Angstroms) and thus do not scatter in the visible range.

Slide 23: Summary

Key take-away points from this presentation are:

- Appearance is determined by interactions with *visible* light
- Selective absorption of blue and green wavelengths by pigment molecules gives our skin its characteristic color
- Suspended clusters ~ 200 nm in size (like traditional ZnO and TiO_2 sunscreen ingredients) scatter visible light strongly. (Maximal scattering occurs as $\lambda = 2^*$ diameter). Scattering causes all colors of visible light to be reflected (back scattered) to our eyes. The combination of all colors of visible light appears white, hence the sunscreen appears white.
- Suspended clusters < 100 nm in size (like nano ZnO and TiO_2 sunscreen ingredients) are too small to scatter visible light. The light passes through the sunscreen to the skin, where the blue and green wavelengths are absorbed, as when no sunscreen is present. The skin appears "skin colored", which is the same as saying that the sunscreen is clear.

Ad Campaign Project: Teacher Instructions #38; Grading Rubric

Overview

In this activity your students will create animations that show how UV and visible light interact with "large" and nano-sized zinc oxide particles. The process of making the many design decisions needed to create the animations will stimulate your students to consider the absorption and scattering processes in depth. Having them work in groups will enhance the activity since they will need to discuss and reconcile their different conceptions of the process. Even if your students have seen scattering animations before, the process of making one will give them the opportunity to integrate and solidify their understanding of the process.

Important: It is very important to review student animations with the whole class at the end of the project so that any parts of the animations that represent the phenomenon incorrectly can be identified and student misconceptions can be corrected. Student will also get to see how the same phenomenon can be represented in multiple ways.

Note: Your students should not have access to an existing scattering animation while they create their own, since this will cause them to replicate existing features without making their own design decisions.

Sunsol, the prominent sunscreen maker, has just decided to launch a new product into the market. The sunscreen will use a zinc oxide (ZnO) nanopowder as its only active ingredient, and will be formulated to go on clear and non-greasy. Sunsol is very excited about its new product, and wants to launch a full ad campaign to promote it to consumers who may not be familiar with the idea of a clear sunscreen that offers full spectrum protection.

Sunsol feels that it is very important for their potential customers to understand both how ZnO interacts with light to protect people's skin and how the size of the particles affects the sunscreen's appearance. For this reason, they have decided that the ad campaign should center on an animated commercial that shows how traditional ZnO and ZnO nanopowders interact with UV and visible light.

Sunsol has invited several creative teams—including yours—to use the ChemSense Animator to create animations showing how the different sized ZnO particles suspended in the sunscreen will scatter visible light differently.

The Request

Sunsol is requesting a total of 4 animations:

1. Sunscreen with ~ 50 nm ZnO particles interacting with UV light.
2. Sunscreen with ~ 50 nm ZnO particles interacting with visible light.
3. Sunscreen with ~ 300 nm ZnO particles interacting with UV light.
4. Sunscreen with ~ 300 nm ZnO particles interacting with visible light.

Your teacher will put you in teams and let you know which of the animations you should work on.

Note: Groups of 2-3 students work well for this assignment.

TABLE 2.31: Animation Matrix

	UV light	Visible Light
50 nm *ZnO* particles	1	2
300 nm *ZnO* particles	3	4

Note: The animations differ in difficulty as follows:

1. Easy (All UV light is absorbed)
2. Difficult (No visible light is scattered; skin absorbs blue/green light, skin appears skin colored)
3. Easy (All UV light is absorbed)
4. Medium (All visible light is scattered, skin appears white)

If time allows, you may want to assign groups to work on both the UV and visible animations for a given size particle (e.g. Animations 1 #38; 2 or 3 #38; 4)

Requirements

Discuss the requirements and student version of the rubric together.

All animations should contain the following elements:

- A light source (the sun)
- A skin surface with sunscreen lotion applied
- *ZnO* particles of the required size suspended in the lotion
- A minimum of 10 frames

The UV light animations should also include:

- At least 2 UVA and 2 UVB light rays interacting with the *ZnO* particles (and skin when appropriate)
- All relevant blocking mechanisms for the *ZnO* particles in the sunscreen

The *visible light* animations should also include:

- At least 5 visible light rays interacting with the *ZnO* particles (and skin when appropriate)
- A human observer and an indication of what the they see

Things to consider in your animation

- How thick will the sunscreen be applied?
- What concentration of particles will the sunscreen have?
- How will you show the different blocking mechanisms?
- How will you indicate what the human observer sees?

Evaluation

Sunsol will evaluate the animations based on the following criteria:

- All required elements are present and accurately depicted
- Animations show correct interaction of light rays with *ZnO* particles (and skin)
- All relevant blocking mechanisms shown (UV light only)
- Animations clearly indicate what the observer sees and why (Visible light only)
- All team member contributed and worked together to produce the animations

Discussion

Important: Your student's animations are models of the scattering phenomenon. In creating them, your students will have made tradeoffs between realism, simplicity, precision and generality. It is important to have your students share their animations and discuss the advantages and limitations of each model (as well as aspects that are inaccurately depicted) so that they do not develop misconceptions about scattering.

Questions to answer about each model:

- How does this model show absorption / scattering?
- How does this model show what the observer sees?
- What are its strengths? (What aspects of scattering does it show particularly well?)
- What are its limitations? (What aspects of scattering are not shown well?)
- Is there anything that seems inaccurately depicted?
- What could be done (within the structure of the animation) to address some of these limitations?

Questions to answer about the group of models as a whole:

- What do the different animations have in common? How do they show things in similar ways?
- What things do the animations show in different ways? Are different animations better at showing different aspects of the phenomenon?
- If different models can be used to represent a phenomenon, how do we know which one is "better"? (Models which best align with or represent the empirical data we have are better.)

TABLE 2.32: Rubric for Ad Campaign Evaluation – UV Light Animations

Category	**Novice (1)** Absent, missing or confused	**Apprentice (2)** Partially developed	**Skilled (3)** Adequately developed	**Masterful (4)** Fully developed
Required Elements • Light source • Skin surface • Sunscreen lotion • Suspended ZnO particles • 2+ UVA rays • 2+ UVB rays • 10+ frames	$0-2$ of the required elements are present.	$3-4$ of the required elements are present.	$5-6$ of the required elements are present.	All 7 required elements are present.
Interactions of light rays with ZnO particles (and skin when appropriate) correctly shown	Few of the required elements are accurately depicted.	Some of the required elements are accurately depicted.	Most of the required elements are accurately depicted.	All of the required elements are accurately depicted.

TABLE 2.32: (continued)

Category	Novice (1) Absent, missing or confused	Apprentice (2) Partially developed	Skilled (3) Adequately developed	Masterful (4) Fully developed
50 nm : • All light is only absorbed • UVA / UVB interact the same 300 nm : • Light is both absorbed and scattered • UVA / UVB interact the same	Few or no key aspects of the interaction are correctly shown.	Some aspects of the interaction are correctly shown.	Most key aspects of the interaction are correctly shown.	All key aspects of the interaction are correctly shown.
All relevant blocking mechanisms correctly shown 50 and 300 nm : • Absorption shows light energy being captured by *ZnO* particles 300 nm only: • Scattering shows light being redirected in multiple directions	Few or no key aspects of the blocking mechanism are correctly shown.	Some key aspects of the blocking mechanism are correctly shown.	Most key aspects of the blocking mechanism are correctly shown.	All key aspects of the blocking mechanism are correctly shown.

TABLE 2.32: (continued)

Category	**Novice (1)** Absent, missing or confused	**Apprentice (2)** Partially developed	**Skilled (3)** Adequately developed	**Masterful (4)** Fully developed
Teamwork • All team members contributed significantly to the project • Group worked together to manage problems as a team	Few team members contributed to the project.	Some team members contributed to the project.	Most team members contributed to the project.	All team members contributed to the project.
	Group did not address the problems encountered.	Group did not manage problems effectively.	Problems in the group managed by one or two individuals.	Group worked together to solve problems.

TABLE 2.33: Rubric for Ad Campaign Evaluation – Visible Light Animations

Category	**Novice (1)** Absent, missing or confused	**Apprentice (2)** Partially developed	**Skilled (3)** Adequately developed	**Masterful (4)** Fully developed
Required Elements • Light source • Human observer • Skin surface • Sunscreen lotion • Suspended ZnO particles • 5+ visible light rays • 10 + frames	$0-2$ of the required elements are present.	$3-4$ of the required elements are present.	$5-6$ of the required elements are present.	All 7 required elements are present.
	Few of the required elements are accurately depicted.	Some of the required elements are accurately depicted.	Most of the required elements are accurately depicted.	All of the required elements are accurately depicted.
Interactions of light rays with ZnO particles (and skin when appropriate) correctly shown				

TABLE 2.33: (continued)

Category	**Novice (1)** Absent, missing or confused	**Apprentice (2)** Partially developed	**Skilled (3)** Adequately developed	**Masterful (4)** Fully developed
50 nm : • No scattering • Blue/green light absorbed by skin • Few or no key aspects of the observer's view are correctly shown. What the observer sees and why they see is correctly shown	Few or no key aspects of the interaction are correctly shown.	Some aspects of the interaction are correctly shown.	Most key aspects of the interaction are correctly shown.	All key aspects of the interaction are correctly shown.
50 nm : • Skin • Peach/Brown color 300 nm : • Sunscreen • White color	Few or no key aspects of the observer's view are correctly shown.	Some key aspects of the observer's view are correctly shown.	Most key aspects of the observer's view are correctly shown.	All key aspects of the observer's view are correctly shown.
Teamwork • All team members contributed significantly to the project • Group worked together to manage problems as a team	Few team members contributed to the project.	Some team members contributed to the project.	Most team members contributed to the project.	All team members contributed to the project.
	Group did not address the problems encountered.	Group did not manage problems effectively.	Problems in the group managed by one or two individuals.	Group worked together to solve problems.

Sunscreens #38; Sunlight Animations: Teacher Instructions #38; Answer Key

This animation worksheet is best used as an in class activity with small groups in order to give students a chance to discuss the different things they notice in the animations. If you have a limited amount of in-class time you may want to do it as a whole class activity or assign it for homework (if all your students have access to the internet) with a follow-up class discussion.

Important: These models are meant to provoke questions and start a discussion about how the scattering mechanism works as well as about the process of making decisions about how to represent things in models. They are not perfect and are not meant to be shown to students simply as an example of "what happens".

Introduction

There are many factors that people take into account when choosing which sunscreen to use and how much to apply. Two of the most important factors that people consider are the ability to block UV and the visual appearance of the sunscreen (due to the interaction with *visible* light). You are about to see three animations that are models of what happens when sunlight (both UV and visible rays) shine on:

- Skin without any sunscreen
- Skin protected by 200 nm ZnO particle sunscreen
- Skin protected by 30 nm ZnO particle sunscreen

Open the animation file as instructed by your teacher and explore the animations for different sunscreen and light ray options. Then choose the sunscreen option and wavelength(s) of light as indicated to answer the following questions.

Viewing the Animations Online:

To view the animations, have your students navigate to the Clear Sunscreen Animation web page at http://nanosense.org/activities/

Downloading the Animations:

If you have a slow Internet connection or want to have a copy of the animation on your computers for offline viewing, go to the Clear Sunscreen Materials web page at http://nanosense.org/activities/clearsunscreen/ and download the files "sunscreenanimation.html" and "sunscreenanimation.swf" to the same folder. To view the animation, simply open the file "sunscreenanimation.html" in your web browser.

Questions

Questions 1 - 2 look at the effects of the UV rays.

Questions 3 – 7 look at the effects of the visible rays.

Questions 8 – 9 ask "what if" questions about changing the animation.

Question 10 asks students to consider the tradeoffs, strengths and limitations of the animations as a model of the interaction of light and sunscreens.

1. Select the UVA and UVB wavelengths of light with no sunscreen and click the play button.

a. What happens to the skin when the UV light reaches it?

The skin is damaged.

b. How is the damage caused by the UVA rays different from the damage caused by the UVB rays? (You may want to play the animation with just UVA or UVB selected to answer this question)

In the animation UVB light causes a burn on the skin's surface and UVA light causes the breakdown in skin fibers deeper in the skin that cause premature aging.

c. Based on what you know about the different energies of UVA and UVB light why do you think this might happen?

The UVB light causes more immediate damage to the first cells it encounters because it is high energy. The UVA light is lower in energy and can penetrate deeper into the skin before it does damage.

Both UVB and UVA light also can lead to DNA mutations that cause cancer which is not shown in the animation.

2. Now leave UVA and UVB light selected and try playing the animation first with the 30 nm ZnO sunscreen and then with the 200 nm ZnO sunscreen.

a. What kind of sunscreen ingredients are shown in each animations?

The 30 nm ZnO is a nanosized inorganic ingredient.

The 200 nm ZnO sunscreen is a traditional inorganic ingredient.

b. What happens to the UV light in the animation of 30 nm ZnO particle sunscreen?

The UV light is completely blocked via absorption.

c. What happens to the UV light in the animation of 200 nm ZnO particle sunscreen?

The UV light is completely blocked via absorption.

d. Is there any difference in how the UV light interacts with the 30 nm ZnO particles versus the 200 nm ZnO particles? Explain why this is so based on your understanding of how the sunscreens work to block UV light.

There is no difference in how the 30 nm and 200 nm ZnO particles interact with the UV light. This is because absorption depends on the energy levels in the substance which are primarily determined by the substance's chemical identity, not the size of the particle.

e. Is there any difference in how the two kinds of UV light interact with the sunscreens? Explain why this is so based on your understanding of how the sunscreens work to block UV light

Both UVA and UVB light are fully absorbed because ZnO absorbs strongly for all wavelengths less than ~ 380 nm .

Students may point out that wavelengths of $380-400$ nm are UVA light that might not be absorbed. This is true and can be discussed at part of the final questions which address the limitations of using models.

3. Select the visible light option and play the animation for each of the sunscreen conditions. What happens to the visible light in each animation and what does the observer see?

a. Skin without any sunscreen

The photons of light pass through the air to the skin. At the skin's surface, most of the blue-green ($\sim 400-550$ nm) wavelengths of light are absorbed by pigments in the skin, while the red-orange-yellow ($\sim 550-700$ nm) wavelengths of light are reflected and reach the observer's eye. The observer sees the surface of the skin. (Different skin colors are caused by different amounts and types of the skin pigment melanin.)

b. Skin with 200 nm Zno particles sunscreen

The photons of light pass through the air and are refracted (bent) as they enter the sunscreen. They are then scattered by the ZnO particles multiple times until they emerge from the sunscreen and are again refracted (bent). Since large particles of ZnO scatter all wavelengths of light equally, all of the different photon wavelengths reach the observer who sees an opaque white surface. (Note that even though the animation shows the different colored photons reaching the observer at different times, in reality there are many photons of each color reaching the observer at the same time.)

c. Skin with 30 nm ZnO particle sunscreen

The photons of light pass through the air and are refracted (bent) as they enter the sunscreen. They pass through ZnO particles without being scattered and at the skin's surface, most of the blue-green ($\sim 400-550$ nm) wavelengths of light are absorbed by pigments in the skin, while the red-orange-yellow ($\sim 550-700$ nm) wavelengths of light are reflected. They then pass through the sunscreen again and are refracted (bent) when they pass to the air before they reach the observer's eye. The observer sees the surface of the skin and we say that the sunscreen is "clear".

4. What determines what the observer sees? (Do they see the skin or the sunscreen? What color do they see?)

You see whatever substance the light touched last before it reaches your eye.

The color is determined by which wavelengths of light are absorbed and which are reflected or scattered.

5. How does scattering affect what the observer sees?

In the no sunscreen and the 30 nm *ZnO* animations the light doesn't scatter. Without scattering, the light that reaches the observer's eyes is the light reflected by the skin (which passes through the sunscreen without being changed) so this is what they see. Since the pigments in the skin absorb blue-green light, skin generally has a reddish color.

When the light scatters (in the 200 nm *ZnO* animation), the light reaching the observers eyes is reflected off of the *ZnO* particles so this is what they see. Since the *ZnO* scatters (and thus reflects) all wavelengths of light equally, it appears white.

6. What variables don't change between the two animations with sunscreens?

The sunscreen solvent, the thickness of the sunscreen layer, the wavelengths of the photons, the identity of the sunscreen's active ingredient, the approximate concentration of the *ZnO* particles (by weight)

7. What variable determines if the visible light scatters or not?

The size of the *ZnO* particles compared to the wavelength of light. Maximum scattering occurs when the particle diameter is one half the wavelength of light ($\sim$ 300 nm for visible light). For particles much smaller than this (e.g. 50 nm), there is very little scattering.

8. What would happen if we applied the large particle sunscreen in a layer only half as thick as the one shown? How would this affect its appearance? How would it affect its UV blocking ability?

Appearance: There will be less *ZnO* particles to scatter the light and so some of the photons will reach the skin layer. The sunscreen would not appear fully white but semitransparent (you would see the skin but it would have a whitish color).

Blocking Ability: Because there are less *ZnO* particles, the sunscreen won't be as effective at blocking UV.

9. What would happen if the observer (eye) moved 3 steps to the left to look at the skin?

Only 5 photons are shown in each animation, but in reality there are many more photons involved both entering and leaving the sunscreen at different angles. Thus there are many photons that never reach the eye of the specific observer shown in the animations. If the observer moves to a new position, they will have different photons reach their eye, but the appearance of the skin / sunscreen remains the same.

10. When we make a model (such as these animations) we make tradeoffs between depicting the phenomenon as accurately as possible and simplifying it to show the key principles involved.

a. Are the different elements of the animation drawn on the same size scale? If not, which ones aren't? How do these affect the animation's ability to depict the scattering mechanism? Which elements in the animation are really on or close to the nanoscale? Which are on the macroscale? Which are on the cosmic scale?

To Scale: Wavelength of light and *ZnO* particle size (this is a key relationship)

Not to Scale: Eye of observer (this is done to show what is seen, but important to note that there are many more photons than shown in the animation and most of them don't reach the observer's eye)

Nanoscale: *ZnO* particles, photons

Macroscale: Skin, sunscreen lotion, observer

Cosmic Scale: Sun

b. What are some other ways these animations have simplified the model of the real world situation they describe?

Example Simplifications:

- The UVA and UVB light is shown as two identical photons when in reality there are many more photons involved.
- The wavelength of the two photons of UVA and UVB light is shown to be the same when in reality each of

these kinds of lights represents a range of wavelengths.
- The ZnO particles are shown as "solid" balls when in reality they are clusters of ions.
- All of the ZnO particles are shown to be the same size, but whenever the particles are produced in reality there is a distribution of particles sizes.
- The damage of the UV rays to the skin doesn't shown the DNA mutations which lead to cancer because of the size and time scale involved.
- The sunscreen solvent is a pale yellow, but it should be clear since it does not scatter (or absorb) light. How else could this be shown in the animations?

c. What are some of the benefits of making a simplified model? What are some of the drawbacks?

Benefits: Easier to see the core of what is going on for particular aspects of the phenomenon; can highlight one particular aspect you want to focus on.

Drawbacks: Viewers won't realize what details are missing and may develop misconceptions about the phenomenon; viewers may also not realize the true complexity of the phenomenon and think that it is simpler than it actually is. There is a tradeoff between realism, precision and generality.

Reflecting on the Guiding Questions: Teacher Instructions #38; Answer Key

You may want to have your students keep these in a folder to use at the end of the unit, or collect them to see how your students' thinking is progressing. You can also have a group discussion about what students learned from the activity that helps them answer the guiding questions.

Discussion Idea:

For each "What I still want to know" section, have students share their ideas and discuss whether their questions are scientific ones or questions of another sort. Scientific questions are questions about how the natural world operates that can be answered through empirical experiments. Other kinds of questions might be ethical in nature (e.g. do friends have a responsibility to persuade friends to use sunscreen?) or policy questions (e.g. should the FDA endorse the most effective sunscreens?).

Think about the activities you just completed. What did you learn that will help you answer the guiding questions? Jot down your notes in the spaces below.

1. What are the most important factors to consider in choosing a sunscreen?

What I learned in this activity:

Possible Answers:

It is also important to choose a sunscreen that we like in terms of appearance to make sure that we use enough of it to be effective.

What I still want to know:

2. How do you know if a sunscreen has "nano" ingredients?

What I learned in this activity:

Possible Answers:

"Nano" ingredients are smaller versions of traditional inorganic ingredients (ZnO and TiO_2).

Traditional ZnO and TiO_2 clusters are $>$ 200 nm in diameter. When clusters are suspended in another medium (like active sunscreen ingredients in the sunscreen lotion) they can scatter light. Light is maximally scattered when its wavelength is twice the diameter of the cluster, so these clusters scatter significantly in the visible range. Some of the scattered light is back-scattered (reflected) back towards our eyes. Since this light is of all visible colors, it combines to appear white.

ZnO and TiO_2 nanoparticles are much small in size with clusters of < 100 nm in diameter. Because of their size, they do not scatter appreciably in the visible range. Since visible light is not scattered by the clusters, it passes through the sunscreen and is reflected by our skin (blue and green rays are absorbed by pigments in the skin and the red, yellow and orange rays are reflected to our eyes) giving skin its characteristic color, thus the sunscreen appear clear.

If a sunscreen contains Zinc Oxide or Titanium Dioxide, but appears clear on our skin, then it likely contains nanoparticles of ZnO or TiO_2 .

What I still want to know:

3. How do "nano" sunscreen ingredients differ from most other ingredients currently used in sunscreens?

What I learned in this activity:

Possible Answers:

Most ingredients currently used in sunscreens are organic ingredients. These are individual molecules that absorb narrow bands of the UVA or UVB spectrum.

"Nano" sunscreen ingredients are inorganic and very similar to traditional inorganic ingredients (large ZnO and TiO_2 clusters); however they appear clear on our skin.

Nano clusters are made up of the same kinds of atoms and have the same formula unit and the larger inorganic clusters, thus they absorb the same kinds of UV light: all wavelengths less than 380 nm (ZnO) or 365 nm (TiO_2) .

However, because the nano inorganic clusters are much smaller in size than traditional inorganic ones (< 100 nm in diameter as opposed to > 200 nm), they don't scatter visible light (maximum scattering occurs at $\lambda = 2 *$ diameter) and thus appear clear on our skin.

What I still want to know:

Culminating Activities

Teacher Lesson Plan

Contents

- Culminating Activities: Teacher Lesson Plan
- Consumer Choice Project: Teacher Instructions #38; Grading Rubric
- The Science Behind the Sunscreen Quiz: Teacher Answer Key
- Clear Sunscreen Final Reflections: Teacher Instructions #38; Answer Key

Orientation

This lesson is designed to have students consolidate their learning and reflect on how their ideas have changed over the course of the unit.

- The Consumer Choice Project is a performance assessment that has students integrate their learning from the unit into a pamphlet to inform consumers about nanoparticulate sunscreens, how they work and their benefits and drawbacks. It includes a teacher grading rubric and peer feedback forms.
- The Science Behind the Sunscreen Quiz is a traditional assessment that asks students a series of closed and open ended questions about the material in the unit.
- The Final Reflections activity asks students to review their reflections from each of the unit activities, answer the essential questions of the unit and compare their current thinking with their thinking from the beginning

of the unit. Students also are asked to identify how their ideas have changed and what things (if any) they are still unsure about. These can serve as final discussion points or ideas for future investigation.

Essential Questions (EQ)

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

1. What are the most important factors to consider in choosing a sunscreen?
2. How do you know if a sunscreen has "nano" ingredients?
3. How do "nano" sunscreen ingredients differ from most other ingredients currently used in sunscreens?

Enduring Understandings (EU)

Students will understand:

(*Numbers correspond to learning goals overview document*)

1. How the energies of different wavelengths of light interact differently with different kinds of matter.

2. Why particle size can affect the optical properties of a material.

3. That there may be health issues for nanosized particles that are undetermined at this time.

4. That it is possible to engineer useful materials with an incomplete understanding of their properties.

6. How to apply their scientific knowledge to be an informed consumer of chemical products.

Key Knowledge and Skills (KKS)

Students will be able to:

(*Numbers correspond to learning goals overview document*)

1. Describe the mechanisms of absorption and scattering by which light interacts with matter.
2. Describe how particle size, concentration and thickness of application affect how particles in a suspension scatter light.
3. Explain how the phenomenon of seeing things in the world is a human visual response depending on how light interacts with objects.
4. Evaluate the relative advantages (strong blockers, UVA protection) and disadvantages (possible carcinogenic effects, not fully researched) of using nanoparticulate sunscreens.

TABLE 2.34: Culminating Activities Timeline (Pamphlet Performance Assessment)

Day	Activity	Time	Materials
Day 1 (50 min)	Hand out the Consumer Choice Project: Student Instructions and walk through the assignment and grading criteria with students. Assign or let students pick the groups or 3 or 4 that they will work in.	10 min	Copies of Consumer Choice Project: Student Instructions
	Have students work in their teams to create the pamphlets. Circulate through the room answering questions and probing student work.	40 min	White paper and colored markers or computers with access to a printer.

TABLE 2.34: (continued)

Day	Activity	Time	Materials
	Homework: Continue to work on the pamphlets • Note: Depending on the depth of student work you may want to extend the activity to a second class period.	30 min	
Day 2 (50 min)	Have students share their pamphlets with the whole class and fill out the peer feedback forms for other teams' pamphlets.	25 min	Copies of Consumer Choice Project: Peer Feedback Form
	Have students work individually or in small groups to fill out the Reflecting on the Guiding Questions: Student Worksheet.	10 min	Copies of Final Reflections: Student Worksheet
	Discuss the Essential Questions and the group's collective ability to answer them based on the work done in the unit and answer any remaining student questions.	15 min	Copies of Final Reflections: Teacher Instruction & Answer Key

TABLE 2.35: Culminating Activities Timeline (Quiz)

Day	Activity	Time	Materials
Day 1 (50 min)	Hand out the quiz and have students work on it on their own.	25 min	Copies of The Science Behind the Sunscreen: Student Quiz
	Have students work individually or in small groups to fill out the Reflecting on the Guiding Questions: Student Worksheet.	10 min	Copies of Final Reflections: Student Worksheet
	Discuss the Essential Questions and the group's collective ability to answer them based on the work done in the unit and answer any remaining student questions.	15 min	Copies of Final Reflections: Teacher Instruction & Answer Key

TABLE 2.35: (continued)

Day	Activity	Time	Materials
Day 2 (15 min)	Hand back the corrected quizzes and go over the answers with students.	15 min	The Science Behind the Sunscreen Quiz: Teacher Answer Key

Consumer Choice Project: Teacher Instructions #38; Grading Rubric

Introduction

SmartShopper, the consumer advocacy group, has heard a lot in the media about the new clear sunscreens with nanoparticulate ingredients coming out on the market. Consumers have been contacting them lately to ask them if these new products are better than traditional sunscreens, if they are safe to use, and how to know if a sunscreen uses nanoparticulate ingredients. To help consumers decide whether these products are right for them, SmartShopper has decided to produce a pamphlet that tells consumers all they need to know about these new products. SmartShopper also will need to take a position on whether or not they endorse the use of the sunscreens and justify this position based on a comparison of the benefits and risks backed up with science. They turn to you and your team to create this pamphlet.

Requirements

SmartShopper asks that your pamphlet makes full use of both sides of an 8.5×11 piece of paper folded into thirds for easy distribution (see "How to Make a Pamphlet") and contains:

- A brief overview of what nanoparticulate sunscreen ingredients are and how they are similar and how they are different from other active sunscreen ingredients.

Nanoparticulate sunscreen ingredients are inorganic UV blockers. This means that they are made out of the same atoms and have an ion lattice structure like standard inorganic sunscreen ingredients, but the particle size (the number of atoms that group together) is much smaller.

They are different from organic UV blockers which are usually conjugated carbon compounds and exist as discrete molecules (i.e. particle size doesn't vary).

- A list of common nanoparticulate active sunscreen ingredients and how to know if your sunscreen contains them.

Zinc Oxide and Titanium Dioxide

The sunscreen may claim "goes on clear" if the nano-versions are used. You can also look at the actual color of applied sunscreen to see if it is the nano-version.

- An explanation of how sunscreens with nanoparticulate ingredients work to block UV light from reaching the skin and the benefits of using them (including advantages over other sunscreen ingredients).

Sunscreens with nanoparticulate ingredients block UV rays by absorbing them. Benefits are full UV coverage, clear appearance and no allergic reactions (traditional inorganic ingredients give full coverage but are not clear (often causing people to use too little); organic ingredients are clear but only block part the UV range and can cause allergic reactions)

- A explanation of why nanoparticulate sunscreen ingredients are clear and a diagram that illustrates the science principles involved.

The opacity of a material depends on the degree to which it scatters light.

Nanoparticles are so much smaller than the wavelength of visible light that they do not scatter it effectively.

Thus, visible light passes through the sunscreen, to the skin's surface where some rays (blue / green) are absorbed and some rays (red / yellow) are reflected. When the receptors in our eyes received by the reflected rays we they produce the image of our skin that we see.

- A transmission versus wavelength graph that supports this explanation.

Students do not need to create this graph themselves – they can use a graph from the unit materials or find one online. The important concept is that they interpret the graph correctly by relating the % transmission at different wavelengths with appearance (white/clear) and UV blocking ability for differently size *ZnO* particles.

- An explanation of the possible downsides / dangers of using sunscreens with nanoparticulate ingredients.

The process of absorption excites an electron (giving it energy) that can lead to side reactions. Some of these side reactions can create to free radicals (particles known to contribute to cancer) or damage DNA. In addition, because nanoparticles are so small, it may be easier for them to penetrate and circulate throughout the body.

The biggest issue with nanoparticulate ingredients is not that they are necessarily more dangerous than other ingredients but that because they are new, they have not been fully researched yet.

- SmartShopper's position on the use of sunscreens nanoparticulate ingredients (do you endorse their use?) with justification of this position based on a comparison of the benefits and risks involved.

How to make a pamphlet

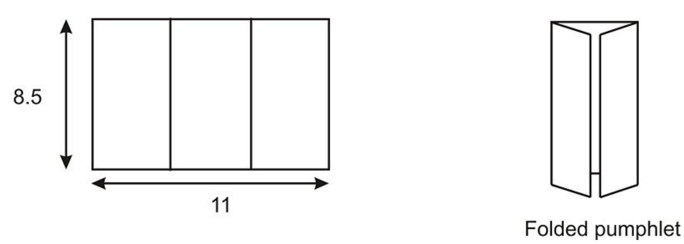
It is up to you how "professional" you want your students to make their pamphlets. If you have two class periods or less to devote to this project, we suggest that you have your students focus on the content and produce "draft versions" of the pamphlet.

By Hand:

Take a regular piece of 8.5×11 paper turn it sideways. Fold the paper into thirds and crease it firmly. This is what the pamphlet will look like when it's done. When you unfold the paper, you can use the creases as column guides. It is good to make the front and back of your pamphlet on different pieces of paper and use a copying machine to make the pamphlet double sided in case you decide to make changes along the way.

With a Computer:

Open a new document in Microsoft Word. Go to File#62;Page Setup to choose a Landscape Orientation and make all of the margins 0.5 inches . Go to Format#62;Columns to choose 3 columns and click the check box for Line Between. You will need to either use a printer that will print double-sided or print the two sides of your pamphlet separately and use a copying machine to make them double sided.



Evaluation

SmartShopper will evaluate the pamphlets based on the following criteria:

- All required information is present and correct
- Scientific explanations are used to back up pamphlets claims
- Effective use of diagram and graph to enhance explanation of why nanoparticulate sunscreen ingredients are clear
- Convincing argument weighing all the relevant information for position taken on nanoparticulate sunscreen use
- All team member contributed and worked together to produce the animations

See full rubric on the last page.

TABLE 2.36: Rubric for Consumer Choice Pamphlet Evaluation

Category	**Novice (1)** Absent, missing or confused	**Apprentice (2)** Partially developed	**Skilled (3)** Adequately developed	**Masterful (4)** Fully developed
Required Information • Overview of nanoingredients • List of common nanoingredients • How UV light is blocked and advantages over other blockers • Why nanoingredients are clear • Visible light scattering diagram • Transmission graph • Possible downsides • Position on use	$0-1$ parts of the required information are present.	$2-4$ parts of the required information are present.	$5-7$ parts of the required information are present.	All 8 parts of the required information are present.
	Few of the required elements are accurately depicted.	Some of the required elements are accurately depicted.	Most of the required elements are accurately depicted.	All of the required elements are accurately depicted.
Pamphlet claims are backed up with accurate scientific explanations	Few of the claims are backed up.	Some of the claims are backed up.	Most of the claims are backed up.	All of the claims are backed up.

TABLE 2.36: (continued)

Category	**Novice (1)** Absent, missing or confused	**Apprentice (2)** Partially developed	**Skilled (3)** Adequately developed	**Masterful (4)** Fully developed
Transmission graph is correctly interpreted • % T is the correctly read from graph • % T correctly related to 1. Visible opacity, 2.UVA blocking and 3. UVB blocking.	1 or none of the key aspects of the graph are correctly interpreted.	2 of the key aspects of the graph are correctly interpreted	3 of the key aspects of the graph are correctly interpreted	All 4 key aspects of the graph are correctly interpreted
Effective use of diagram to show visual transparency of sunscreen • Diagram includes sun, photons, skin, nanoparticle sunscreen, skin, and observer • No scattering of visible light • Skin absorbs blue/green light • Observer sees red/yellow skin	1 or none of the key aspects of the interaction are correctly shown.	2 of the key aspects of the interaction are correctly shown.	3 of the key aspects of the interaction are correctly shown.	All 4 key aspects of the interaction are correctly shown.

TABLE 2.36: (continued)

Category	**Novice (1)** Absent, missing or confused	**Apprentice (2)** Partially developed	**Skilled (3)** Adequately developed	**Masterful (4)** Fully developed
Convincing argument to support position on nanoparticulate sunscreen use • Uses all available information • Information interpreted with respect to user concerns • Both pros and cons considered • Justification for position taken	$0-1$ key aspects of the argument are given effectively.	2 key aspects of the argument are given effectively.	3 key aspects of the argument are given effectively.	All 4 key aspects of the argument are given effectively.
Teamwork • All team members contributed significantly to the project • Group worked together to manage problems as a team	Few team members contributed to the project.	Some team members contributed to the project.	Most team members contributed to the project.	All team members contributed to the project.
	Group did not address the problems encountered.	Group did not manage problems effectively.	Problems in the group managed by one or two individuals.	Group worked together to solve problems.

The Science Behind the Sunscreen Quiz: Teacher Answer Key

1. Why is UV light a source of health concern when visible and infrared light are not? (*2 points*)

- UV light is a higher frequency light than visible and infrared and thus has a higher energy per photon.
- This higher energy allows it to do damage even though the total amount of UV light reaching the earth is less than for visible and infrared light.

2. List 2 kinds of damage to the body caused by UV radiation. (2 *points*)

Any of the following four answers are acceptable.

- Sunburn
- Pre-mature skin aging
- Skin cancer
- Cataracts

3. Explain in your own words why it is important to block UVA light. (2 *points*)

- Even though it does not cause short-term damage like sunburns, UVA light has been found to cause long term damage including premature skin aging and skin cancer.
- It is especially dangerous because it has been found to penetrate more deeply into the skin than UVB light and because the effects are not immediately apparent, we may not realize that damage is being done.

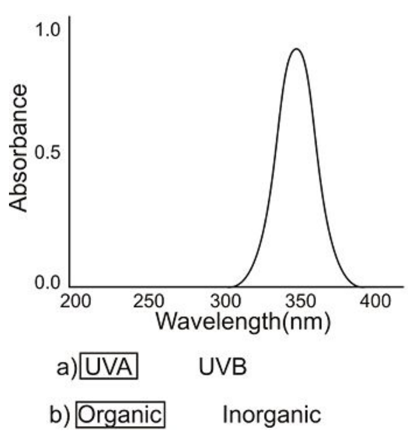
4. How do you know if a sunscreen protects against UVA light (now and future)? (2 *points*)

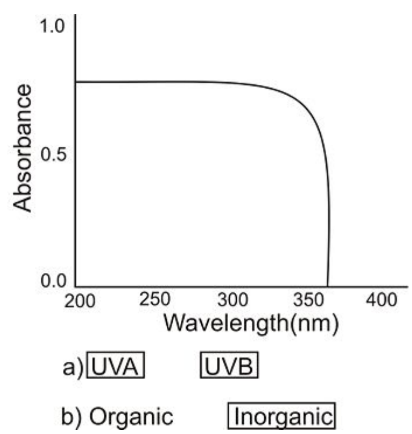
- Currently, the only way to tell how well a sunscreen protects against UVA rays is by looking at the ingredients and knowing which ones absorb UVA light.
- A new FDA rating for UVA light based on a 4− star system should be implemented in the next few years (more stars will equal greater UVA protection).

5. How do you know if a sunscreen protects against UVB light? (1 *points*)

- A sunscreen's SPF (Sunburn Protection Factor) number indicates its ability to absorb UVB light (a higher number equals greater UVB protection).

6. For each of the following absorption graphs, circle the correct answers for a) what kind(s) of light are strongly absorbed and b) whether it is an organic or inorganic sunscreen. (4 *points*)





7. Why do sunscreens that use nano-sized TiO_2 clusters appear clear on our skin while sunscreens that use traditional sized TiO_2 clusters appear white? (5 *points*)

- Suspended clusters scatter light maximally for wavelengths twice as large as their diameter.
- Since visible light has $\lambda \approx 400-800$ nm , cluster with a diameter of $200-400$ nm (such as traditional TiO_2) scatter much visible light.
- The scattered rays that are reflected towards our eyes are of all colors in the spectrum, making the sunscreen appear white.

- Clusters smaller than 100 nm in diameter (such as nano TiO_2) do not scatter appreciably in the visible range.
- The visible light passes through the sunscreen and is reflected by our skin. Thus our skin color is what we see, making the nano-sized TiO_2 particles effectively clear.

8. How do you know if a sunscreen has "nano" ingredients? (2 *points*)

- Contains inorganic ingredients (ZnO or TiO_2)
- Sunscreen appears clear on the skin.

9. Briefly describe one benefit and one drawback of using a sunscreen that contains "nano" ingredients: (1 *point each, a total of* 2 *points*)

Benefits (*Either of the following answers is acceptable*)

- Block whole UV spectrum
- Appear clear, people less likely to underapply

Drawbacks (*Either of the following answers is acceptable*)

- New chemicals not fully studied; possible harmful effects still unknown. FDA is not treating nano-versions of known chemicals as new; needed health studies may not occur.
- Very small particles are more likely to cross membranes and get into unintended parts of the body

10. In what ways are "nano" sunscreen ingredients similar and different from other ingredients currently used in sunscreens? For each of the four categories below, indicate whether "nano" sunscreen ingredients are "similar" or "different" to organic and inorganic ingredients and explain how. (1 *point each, total of* 8 *points*)

TABLE 2.37:

	Organic Ingredients (e.g. PABA)	Inorganic Ingredients (e.g. Classic Zinc Oxide used by lifeguards)
Chemical Structure	Similar or **Different** How: Nano ingredients are small ionic clusters while organic ingredients are molecules.	**Similar** or Different How: Nano ingredients are a kind of inorganic ingredients. Bother are ionic clusters but the nano clusters are smaller.
Kinds of Light Blocked	Similar or **Different** How: Organic ingredients each block a small part of the UV spectrum (generally UVB) while nano ingredients block almost the whole thing,	**Similar** or Different How: Both nano ingredients and traditional inorganic ingredients block almost the whole UV spectrum.
Way Light is Blocked	**Similar** or Different How: Both nano and organic ingredients block UV light via absorption. (The specific absorption mechanism is different, but students are not expected to report this)	**Similar** or Different How: Both nano and inorganic ingredients block UV light via absorption.
Appearance on the Skin	**Similar** or Different How: Both nano and organic ingredients appear clear on the skin.	Similar or **Different** How: Traditional inorganic ingredients appear white on the skin while nano ingredients appear clear.

Clear Sunscreen Final Reflections: Teacher Instructions #38; Answer Key

The goal of this exercise is for students to reflect on their learning and evaluate how their ideas and their confidence in them has changed since the unit began. The answers to the questions on page two are also a final check for you to see where students are and if they have any misconceptions that need to be addressed. Possible student answers are listed below, these are compiled based on completion of the entire unit. If you have only done selected lessons with your class, some of the answers many not apply. Please refer to the teacher's version of the reflection sheets associated with each lesson for lesson-specific answers.

Now that you have come to the end of the unit, go back and look at the reflection forms you filled out after each activity and try to answer the guiding questions below. Write down answers each question below and then evaluate how confident you feel that each idea is true.

TABLE 2.38:

1. What are the most important factors to consider in choosing a sunscreen? It is important to choose a sunscreen that provides good protection against both UVA and UVB. A sunscreen's SPF number tells us how well the sunscreen protects against UVB rays. For UVA protection, until the new FDA rating is approved, the only way to tell how well a sunscreen protects against UVA rays is by looking at the ingredients. Inorganic ingredients (ZnO and TiO_2) absorb both UVA and UVB, so sunscreens that include them have broadband protection.	**How sure are you that this is true?** Not to Sure	**How sure are you that this is true?** Kind-of Sure	**How sure are you that this is true?** Very Sure

TABLE 2.38: (continued)

1. What are the most important factors to consider in choosing a sunscreen? Organic ingredients each block a specific wavelength range that can be in the UVA or UVB range. To ensure broadband protection, it is important to choose a sunscreen that has a combination of ingredients that will absorb both kinds of light. Avobenzone and Ecamsule are the two FDA approved organic ingredients that absorb strongly across the UVA range. It is also important to choose a sunscreen that we like in terms of appearance and smell to make sure that we use enough of it to be effective.	**How sure are you that this is true?** Not to Sure	**How sure are you that this is true?** Kind-of Sure	**How sure are you that this is true?** Very Sure

TABLE 2.39:

2. How do you know if a sunscreen has "nano" ingredients? "Nano" ingredients are smaller versions of traditional inorganic ingredients (ZnO and TiO_2) that go on clear. If a sunscreen contains Zinc Oxide or Titanium Dioxide, but appears clear on our skin, then it likely contains nanoparticles of ZnO or TiO_2 .	**How sure are you that this is true?** Not to Sure	**How sure are you that this is true?** Kind-of Sure	**How sure are you that this is true?** Very Sure

TABLE 2.39: (continued)

2. How do you know if a sunscreen has "nano" ingredients? Traditional ZnO and TiO_2 clusters appear white because they are >200 nm in diameter and thus scatter all colors of visible light back towards our eyes. (Maximum scattering occurs at $\lambda = 2*$ diameter). ZnO and TiO_2 nanoparticles are <100 nm in diameter and thus do not scatter appreciably in the visible range. The visible light passes through the sunscreen and is reflected by our skin, thus the sunscreen appear clear.	**How sure are you that this is true?** Not to Sure	**How sure are you that this is true?** Kind-of Sure	**How sure are you that this is true?** Very Sure

TABLE 2.40:

3. How do "nano" sunscreen ingredients differ from most other ingredients currently used in sunscreens? Most ingredients currently used in sunscreens are organic ingredients. These are individual molecules that absorb narrow bands of the UVA or UVB spectrum.	**How sure are you that this is true?** Not to Sure	**How sure are you that this is true?** Kind-of Sure	**How sure are you that this is true?** Very Sure

TABLE 2.40: (continued)

3. How do "nano" sunscreen ingredients differ from most other ingredients currently used in sunscreens? "Nano" sunscreen ingredients are inorganic and very similar to traditional inorganic ingredients (large ZnO and TiO_2 clusters) – they are made up of the same kinds of atoms and have the same formula unit, thus they absorb strongly in both the UVA and UVB range up to their cutoff wavelength: 380 nm (ZnO) or 365 nm (TiO_2) . However, because the nano inorganic clusters are much smaller in size than traditional inorganic ones ($<$ 100 nm in diameter as opposed to $>$ 200 nm), they don't scatter visible light (maximum scattering occurs at $\lambda = 2 *$ diameter) and thus appear clear on our skin.	**How sure are you that this is true?** Not to Sure	**How sure are you that this is true?** Kind-of Sure	**How sure are you that this is true?** Very Sure

Now go back to the worksheet you filled out with your initial ideas at the beginning of the unit and mark each idea with a $\surd$ if you still believe it is true, an X if you don't think that it is true and a ? if you are still unsure. Then answer the following questions.

1. What ideas do you have now that are the same as when you started?
2. What ideas are different and how?
3. What things are you still unsure about?

One-Day Version of Clear Sunscreen

Teacher Lesson Plan

Contents

- One-Day Version of Clear Sunscreen: Teacher Lesson Plan

- NanoSunscreen: The Wave of the Future?: PowerPoint Slides and Teacher Notes

Orientation

This abridged version of the Clear Sunscreen unit provides a one-day overview of the science behind nanosunscreens for teachers with limited time. This version is specifically designed for students who have a significant background in chemistry, physics and biology; while it covers a large amount of content, most of the ideas and concepts presented should be familiar to students from their other science classes.

The goal of this lesson is to give student an overview of the dangers of sun radiation, how sunscreens work to protect us, and what determines how they appear on our skin, with a focus on the particular case of nanosunscreens. The lesson is structured around a central PowerPoint, and has a demonstration, an animation, and several student handouts to support learning.

- The NanoSunscreen – The Wave of the Future? PowerPoint starts by explaining the dangers of sun radiation and the need to use sunscreen to protect our bodies. A brief introduction to the different kinds of electromagnetic waves and their energies sets the stage for differentiating between the two kinds of UV light that we need to protect our bodies from (UVA and UVB). The PowerPoint then takes students through the history of why sunscreens were first developed, their current rating system for UVB blocking ability (SPF) and the need to also consider UVA blocking ability. Next, the slides explore the different structure and blocking mechanisms of organic and inorganic sunscreen ingredients. Finally the slides discuss what gives inorganic sunscreens their "white" or clear appearance and how the nano versions remedy this situation.
- There is an optional demonstration of absorption of UV light by chemicals in printed money (as an anti-counterfeiting measure) embedded in the PowerPoint presentation that you can do with your class.
- There is an optional animation that illustrates the process of how UV and visible light interacts with sunscreen and our skin. This animation can be downloaded from the NanoSense website at http://nanosense.org/activities/clearsunscre
- Three Student Handouts are provided to support the concepts introduced in the PowerPoint.

Essential Questions (EQ)

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

- What are the most important factors to consider in choosing a sunscreen?
- How do you know if a sunscreen has "nano" ingredients?
- How do "nano" sunscreen ingredients differ from most other ingredients currently used in sunscreens?

Enduring Understandings (EU)

Students will understand:

(*Numbers correspond to learning goals overview document*)

1. How the energies of different wavelengths of light interact differently with different kinds of matter.

2. Why particle size can affect the optical properties of a material.

3. That there may be health issues for nanosized particles that are undetermined at this time.

6. How to apply their scientific knowledge to be an informed consumer of chemical products.

Key Knowledge and Skills (KKS)

Students will be able to:

(*Numbers correspond to learning goals overview document*)

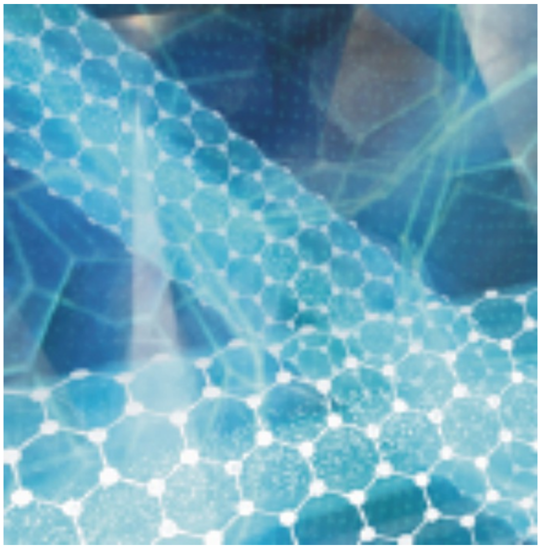
1. Describe the mechanisms of absorption and scattering by which light interacts with matter.
2. Describe how particle size, concentration and thickness of application affect how particles in a suspension scatter light.

3. Explain how the phenomenon of seeing things in the world is a human visual response depending on how light interacts with objects.
4. Evaluate the relative advantages (strong blockers, UVA protection) and disadvantages (possible carcinogenic effects, not fully researched) of using nanoparticulate sunscreens.

TABLE 2.41: Timeline

Day	Activity	Time	Materials
Day 1 (50 min)	Show NanoSunscreen – The Wave of the Future? PowerPoint Slides, using the question slides and teacher's notes to start class discussion. Perform Demonstration associated with PowerPoint Presentation (optional). Show Animation associated with PowerPoint Presentation (optional). Give out student handouts and discuss as at appropriate parts of the presentation: • Sun Radiation Summary • Summary of FDA Approved Sunscreen Ingredients • Overview of Sunscreen Ingredients	50 min	NanoSunscreen – The Wave of the Future? PowerPoint Slides & Teacher Notes Computer and projector Optional Demonstration Materials: UV light, different kinds of paper currency. Optional Animation: Download from http://nanosense.org/activities/clearsuns Copies of Student Handouts

NanoSunscreen



The Wave of the Future?

Part1

Understanding the Danger

Why use sunscreen?

Too Much Sun Exposure is Bad for Your Body

- Premature skin aging (wrinkles)
- Sunburns
- Skin cancer
- Cataracts

Skin Cancer Rates are Rising Fast

Skin cancer:

- $\sim$ 50% of all cancer cases
- $>$ 1 million cases each year
- $\sim$ 1 person dies every hour

Causes of the increase:

- Decrease ozone protection
- Increased time in the sun
- Increased use of tanning beds

What are sun rays?

How are they doing damage?

The Electromagnetic Spectrum

- Sun rays are electromagnetic waves
  - Each kind has a wavelength, frequency and energy

FIGURE 2.83

FIGURE 2.84

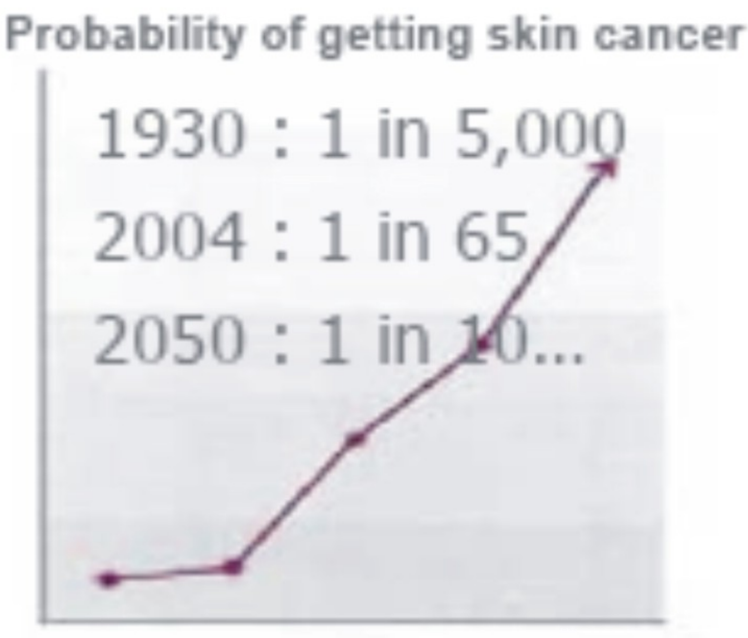

Probability of getting skin cancer
1930 : 1 in 5,000
2004 : 1 in 65
2050 : 1 in 10...

FIGURE 2.85

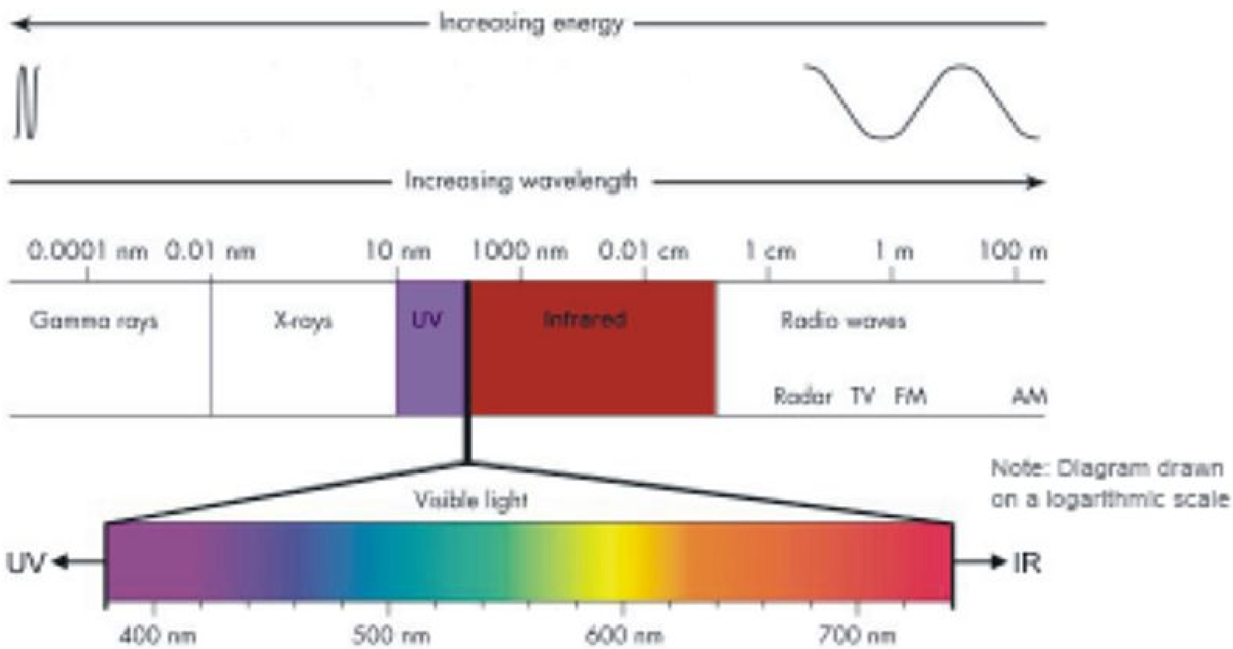


FIGURE 2.86

The Sun's Radiation Spectrum I

- The sun emits several kinds of electromagnetic radiation
  - Infrared (IR), Visible (Vis), and Ultra Violet (UV)

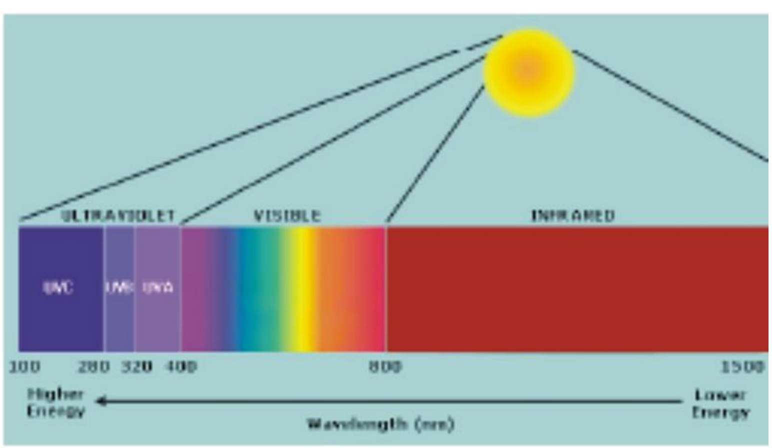


FIGURE 2.87

- Higher energy radiation can damage our skin

The Sun's Radiation Spectrum II

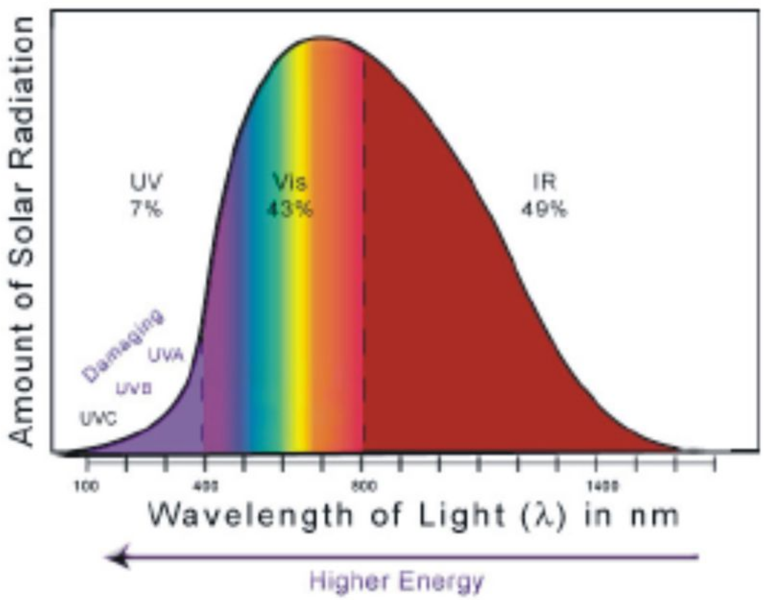


FIGURE 2.88

- How much UV, Vis #38; IR does the sun emit?

How can the sun's rays harm us?

Sun Rays are Radiation

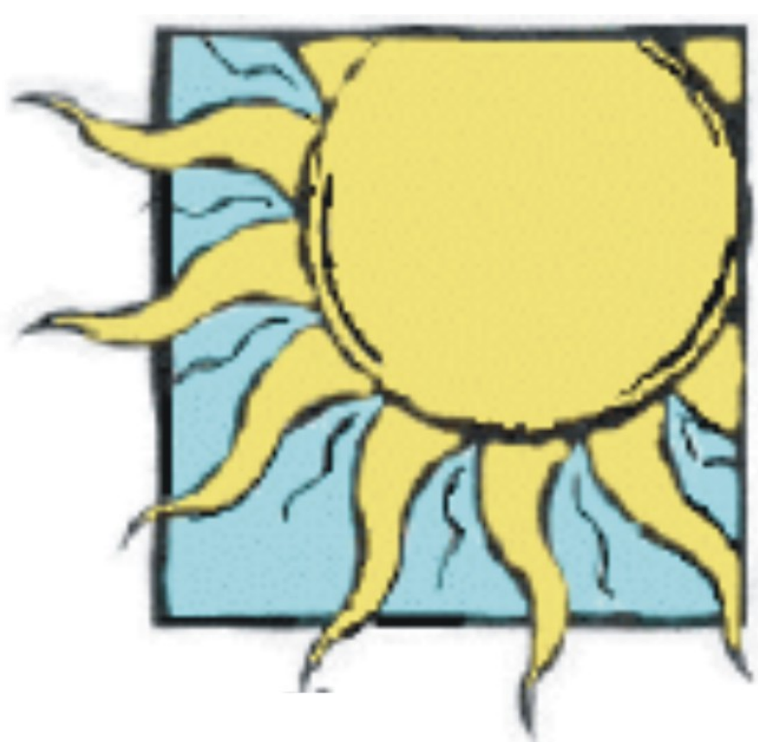


FIGURE 2.89

- Light radiation is often thought of as a wave with a wavelength (λ) and frequency (f) related by this equation:

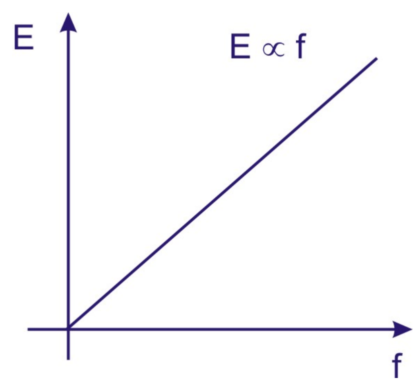
$$C = \lambda \times f$$

- Since c (the speed of light) is constant, the wavelength and frequency are inversely related

$$\lambda = \frac{c}{f} \qquad f = \frac{c}{\lambda}$$

- This means that light with a short wavelength will have a high frequency and visa versa

Radiation Energy I



1. Energy Comes in Packets

- The size of an energy packet (E) is determined by the frequency of the radiation (f)

$$E = h \times f$$

- Radiation with a higher frequency has more energy in each packet
- The amount of energy in a packet determines how it interacts with our skin

Radiation Energy II

2. Total Energy

- This relates not only to how much energy is in each packet but also to the total number of packets arriving at a given location (such as our skin)
- Total Energy depends on many factors including the intensity of sunlight
- The UV Index rates the total intensity of UV light for many locations in the US daily: http://www.epa.gov/sunwise/uvindex.

Skin Damage I

- The kind of skin damage is determined by the size of the energy packet $(E = h * f)$
- The UV spectrum is broken into three parts:

FIGURE 2.90

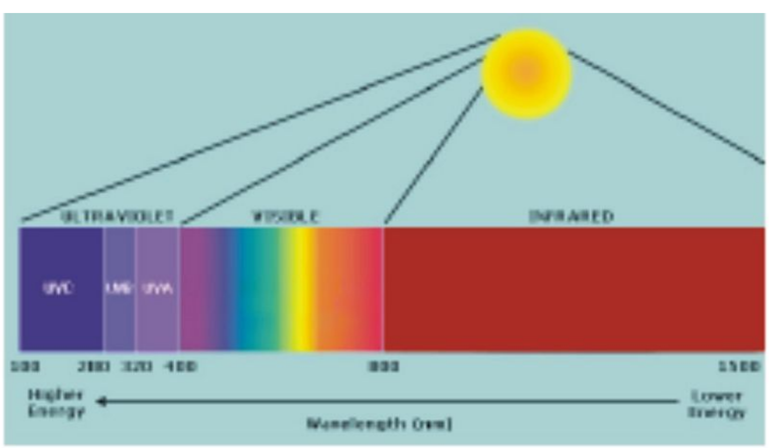


FIGURE 2.91

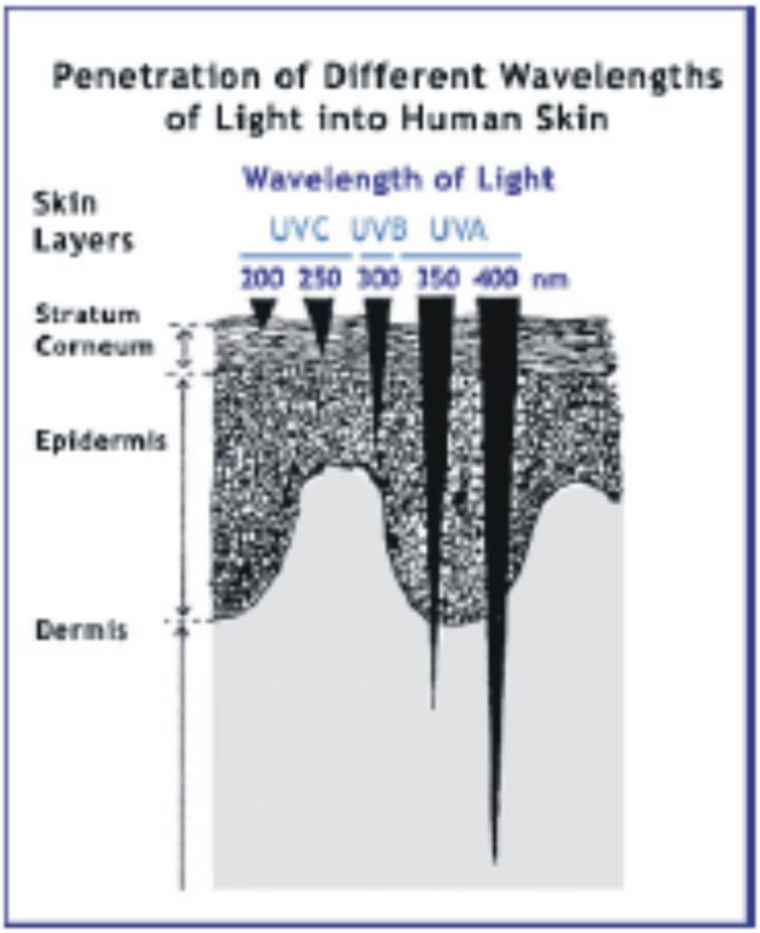


FIGURE 2.92

N.A. Shaath. The Chemistry of Sunscreens. In Lowe NJ Shaath NA Pathak MA editors. Sunscreens development evaluation and regulatory aspects. New York Marcel Dekker 1997. p. 263-283.

  - Very High Energy (UVC)
  - High Energy (UVB)
  - Low Energy (UVA)
- As far as we know, visible and IR radiation don't harm the skin

Skin Damage II

- Very high energy radiation (UVC) is currently absorbed by the ozone layer
- High energy radiation (UVB) does the most immediate damage (sunburns)
- Lower energy radiation (UVA) can penetrate deeper into the skin, leading to long term damage

Sun Radiation Summary I

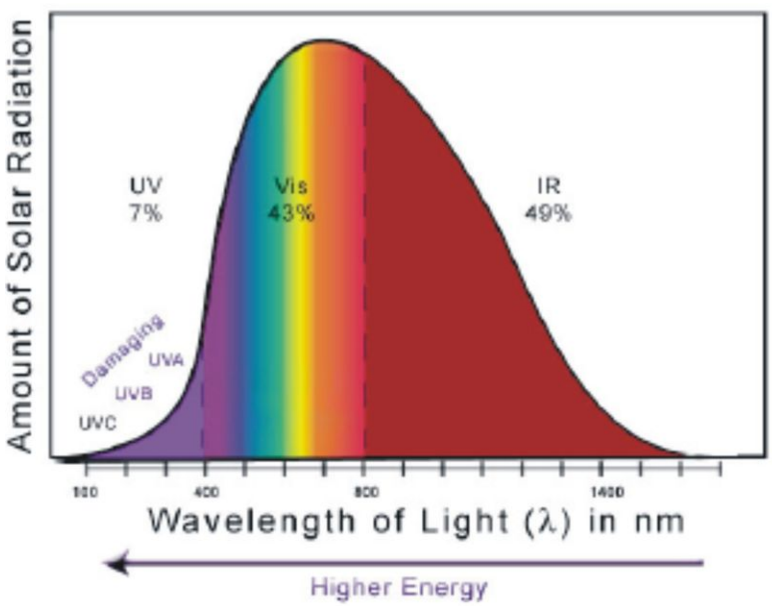


FIGURE 2.93

TABLE 2.42: Sun Radiation Summary II

Radiation Type	Characteristic Wavelength (λ)	Energy per Photon	% of Total Radiation Emitted by Sun	Effects on Human Skin	Visible to Human Eye?
	Increasing wavelength	**Decreasing Energy**			
UVC	∼ 200 – 290 nm (Short-wave UV)	High Energy	∼ 0% (< 1% of all UV)	DNA Damage	No
UVB	∼ 290 – 320 nm (Mid-range UV)	Medium Energy	∼ .35% (5% of all UV)	Sunburn DNA Damage Skin Cancer	No
UVA	320 – 400 nm (Long-wave UV)	Low Energy	∼ 6.5% (95% of all UV)	Tanning Skin Aging DNA Damage Skin Cancer	No

TABLE 2.42: (continued)

Radiation Type	Characteristic Wavelength (λ)	Energy per Photon	% of Total Radiation Emitted by Sun	Effects on Human Skin	Visible to Human Eye?
Vis	$\sim 400-800$ nm	Lower Energy	$\sim 43\%$	None Currently Known	Yes
IR	$\sim 800-120,000$ nm	Lowest Energy	$\sim 49\%$	Heat Sensation (high λ IR)	No

Part2

Protecting Ourselves

What do Sunscreens Do?

- Sunscreens are designed to protect us by preventing UV rays from reaching our skin
- But what does it mean to ”block” UV rays?

Light Blocking

- Anytime light interacts with some material, 3 things can happen. The light can be transmitted, it can be reflected, or it can be absorbed

- If we say that light is “blocked” it means that it is either absorbed or reflected by the material
  - Sunscreens mainly block via absorption

A Brief History of Sunscreens: The Beginning

- First developed for soldiers in WWII (1940s) to absorb “sunburn causing rays”

A Brief History of Sunscreens: The SPF Rating

- Sunscreens first developed to prevent sunburn
  - Ingredients were good UVB absorbers
- SPF Number (Sunburn Protection Factor)
  - Measures the strength of UVB protection only
  - Higher SPF # = more protection from UVB
  - Doesn’t tell you anything about protection from UVA

A Brief History of Sunscreens: The UVA Problem

- UVA rays have no immediate visible effects but cause serious long term damage
  - Cancer
  - Skin aging
- Sunscreen makers working to find UVA absorbers
- *NEW:* The FDA has just proposed a 4− star UVA rating to be included on sunscreen labels!

FIGURE 2.94

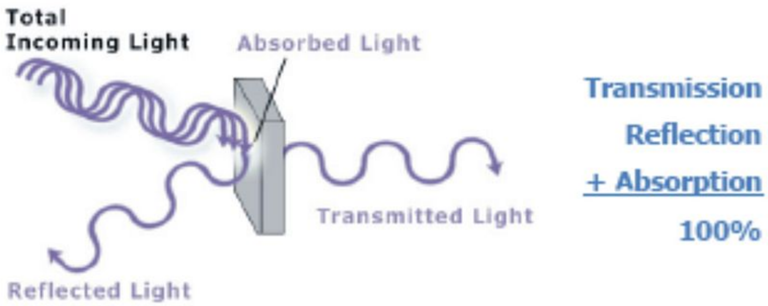


FIGURE 2.95

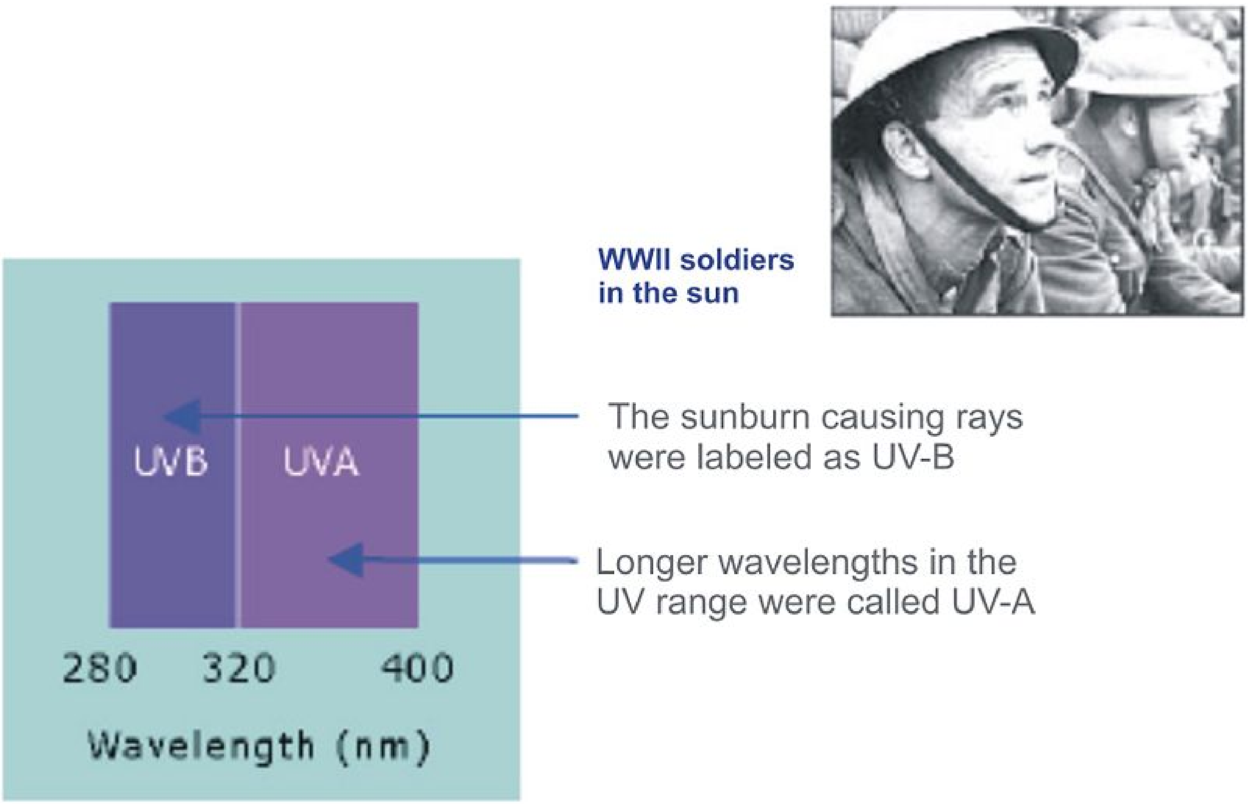

WWII soldiers
in the sun
UVB
UVA
The sunburn causing rays
were labeled as UV-B
Longer wavelengths in the
UV range were called UV-A
280
320
400
Wavelength (nm)

FIGURE 2.96


SolBar PF
LIQUID
30
PROTECTION
SolBar PF
50
SUNSCREEN
PROTECTION

FIGURE 2.97

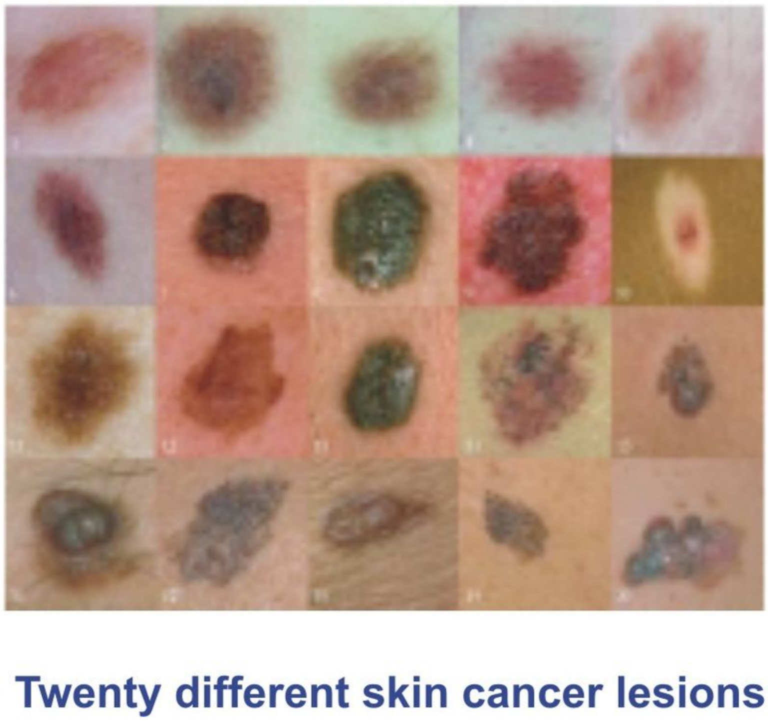


FIGURE 2.98

FIGURE 2.99

FIGURE 2.100

Low ⋆⋆⋆⋆ Med ⋆⋆⋆⋆ High ⋆⋆⋆⋆ Highest ⋆⋆⋆⋆

How do you know if your sunscreen is a good UVA blocker?

Know Your Sunscreen: Look at the Ingredients

- UV absorbing agents suspended in a lotion
  - "Colloidal suspension"
- Lotion has "inactive ingredients"
  - Don't interact w/ UV light
- UV absorbing agents are "active ingredients"
  - Usually have more than one kind present
- Two kinds of active ingredients
  - Organic ingredients and inorganic ingredients

TABLE 2.43: **Sunscreen Ingredients Overview**

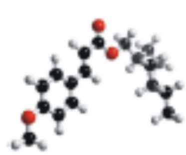
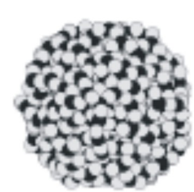
	Organic Ingredients	Inorganic Ingredients
Atoms Involved	Carbon, Hydrogen, Oxygen, Nitrogen	Zinc, Titanium, Oxygen
Structure (not drawn to scale)	Individual molecule 	Clusters of various size 

TABLE 2.43: (continued)

	Organic Ingredients	Inorganic Ingredients
UV Blocking	Absorb specific bands of UV light	Absorb all UV with $\lambda <$ critical value
Appearance	Clear	Large clusters = White Small clusters = Clear

Organic Ingredients: The Basics

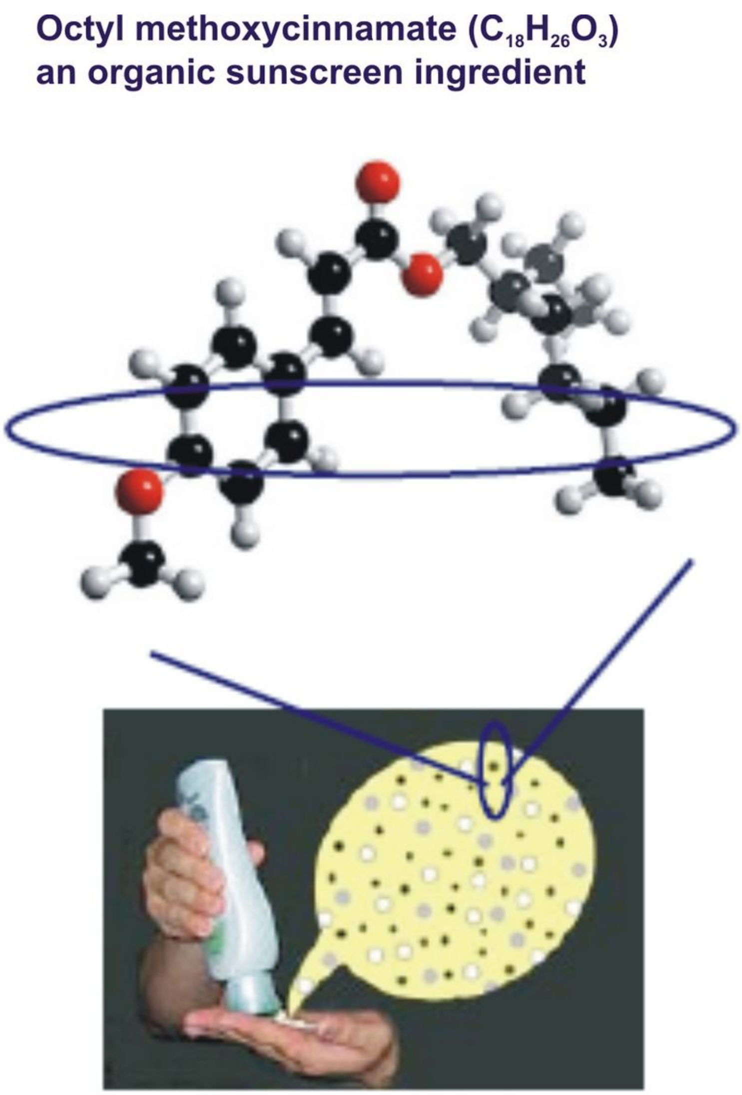


FIGURE 2.101

- Organic = Carbon Compounds
  - H, O #38; N atoms often involved
- Structure
  - Covalent bonds
  - Exist as individual molecules

- Size
  - Molecular formula determines size (states the number and type of atoms in the molecule)
  - Typically a molecule measures a few to several dozen Å (< 10 nm)

Organic Ingredients: UV Blocking

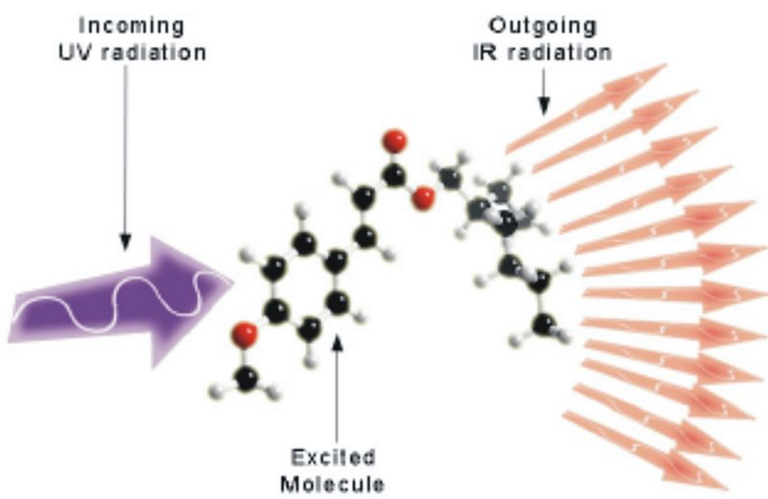


FIGURE 2.102

1. Molecules capture energy from the sun's UV rays
2. The energy give the molecule thermal motion (vibrations and rotations)
3. The energy is reemitted as harmless long wave IR

Organic Ingredients: Absorption Range

- Organic molecules only absorb UV rays whose energy matches the difference between the molecule's energy levels
  - Different kinds of molecules have different peaks and ranges of absorption
  - Using more than one kind of ingredient (molecule) gives broader protection

Organic Ingredients: Absorbing UVA / UVB

- Most organic ingredients that are currently used were selected because they absorb UVB rays
  - The FDA has approved 15 organic ingredients
  - 13 of these primarily block UVB rays
- Sunscreen makers are working to develop organic ingredients that absorb UVA rays
  - Avobenzone and Ecamsule are good FDA approved UVA absorbers

How are inorganic sunscreen ingredients different from organic ones?

How might this affect the way they absorb UV light?

Inorganic Ingredients: The Basics

- Atoms Involved

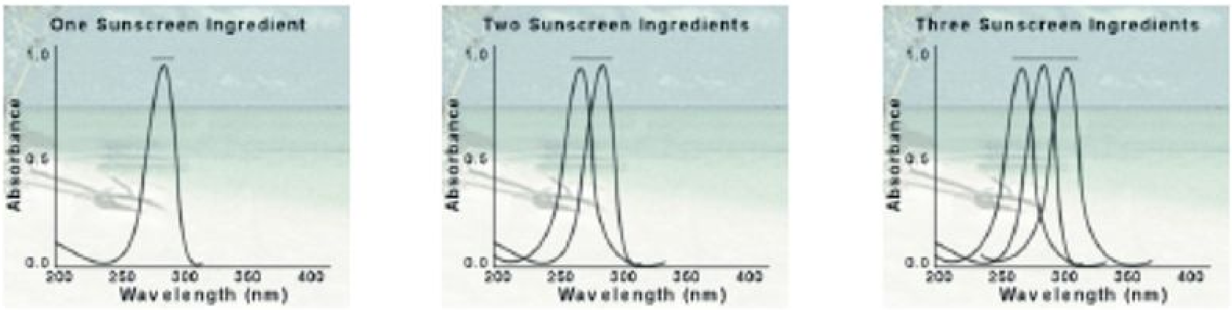


FIGURE 2.103

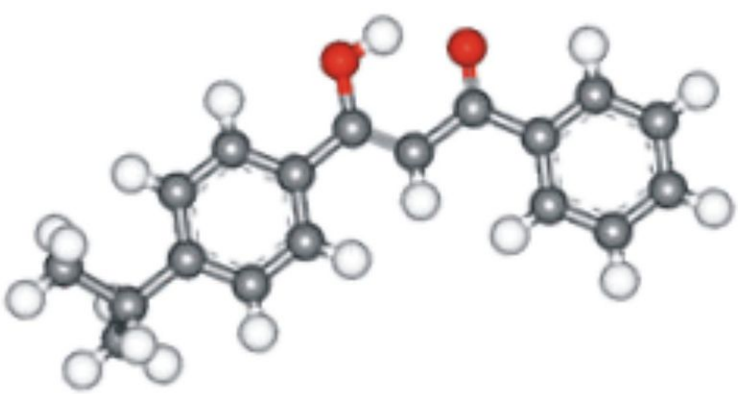


FIGURE 2.104

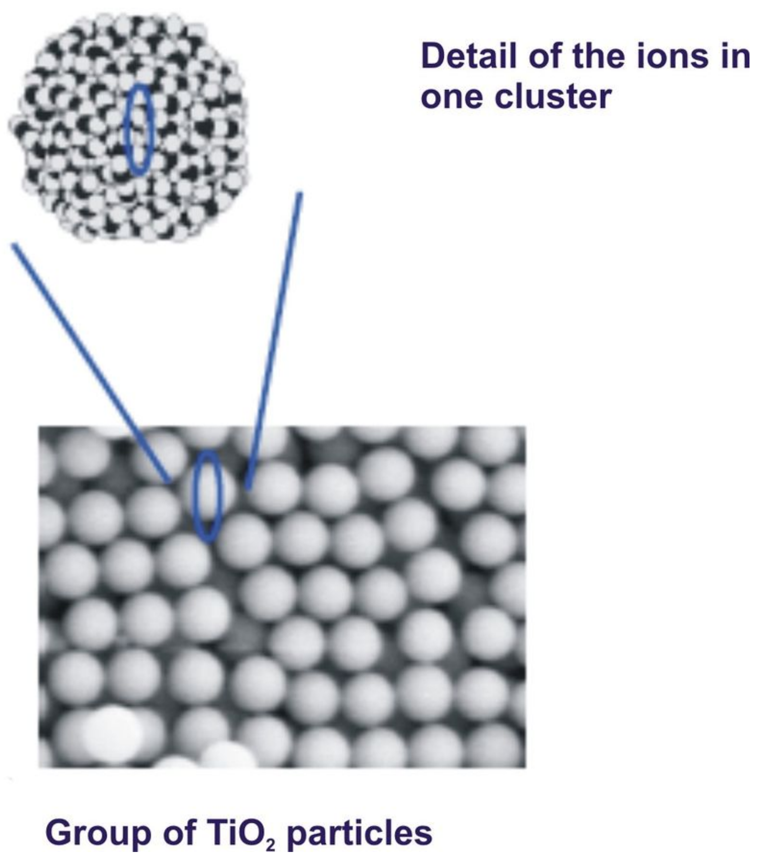


FIGURE 2.105

- Zinc or Titanium
- Oxygen

- Structure
  - Ionic attraction
  - Cluster of ions
  - Formula unit doesn't dictate size
- Size
  - Varies with # of ions in cluster
  - Typically ∼ 10 nm – 300 nm

Inorganic Ingredients: Cluster Size

- Inorganic ingredients come in different cluster sizes (sometimes called "particles")
  - Different number of ions can cluster together
  - Must be a multiple of the formula unit
  - ZnO always has equal numbers of Zn and O atoms
  - TiO_2 always has twice as many O as Ti atoms

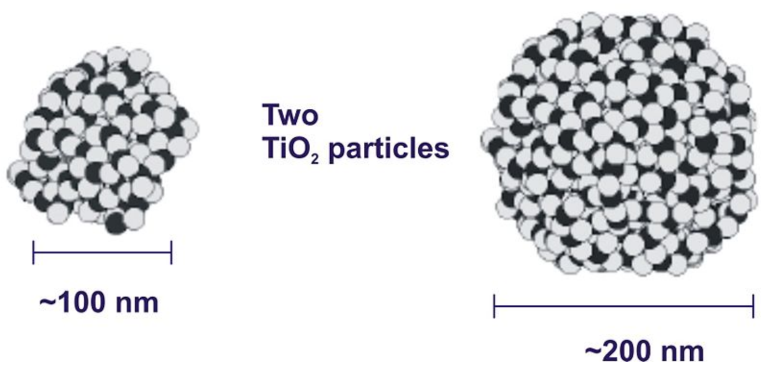


FIGURE 2.106

Inorganic Ingredients: UV Blocking

- Inorganic Sunscreen Ingredients can also absorb UV rays
  - But a different structure leads to a different absorption mechanism
  - Absorb consistently through whole UV range up to ∼ 380 nm
  - How is the absorption pattern different than for organics?

If inorganic sunscreen ingredients block UVA light so well, why doesn't everybody use them?

Appearance Matters

- Traditional inorganic sunscreens appear white on our skin
- Many people don't like how this looks, so they don't use sunscreen with inorganic ingredients
- Of the people who do use them, most apply too little to get full protection

Why Do They Appear White? I

- Traditional ZnO and TiO_2 clusters are large

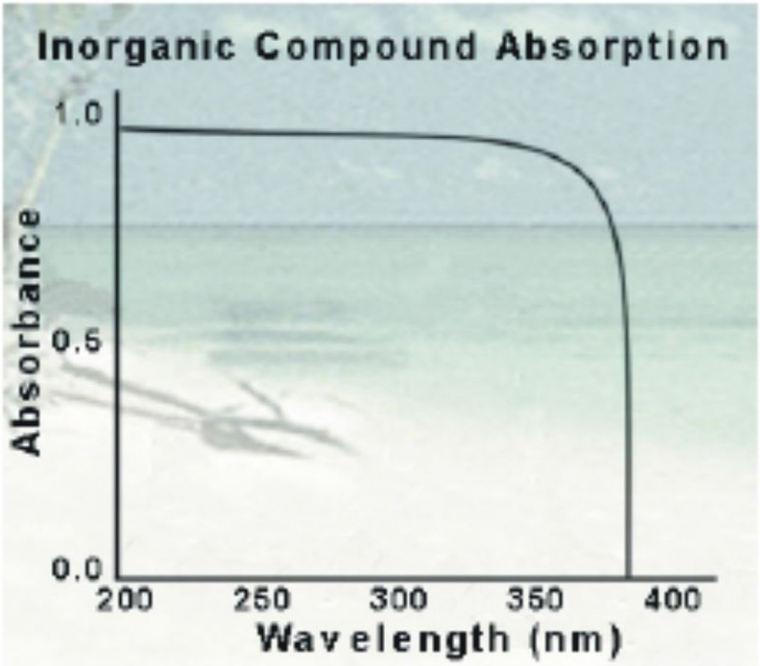


FIGURE 2.107

FIGURE 2.108

FIGURE 2.109

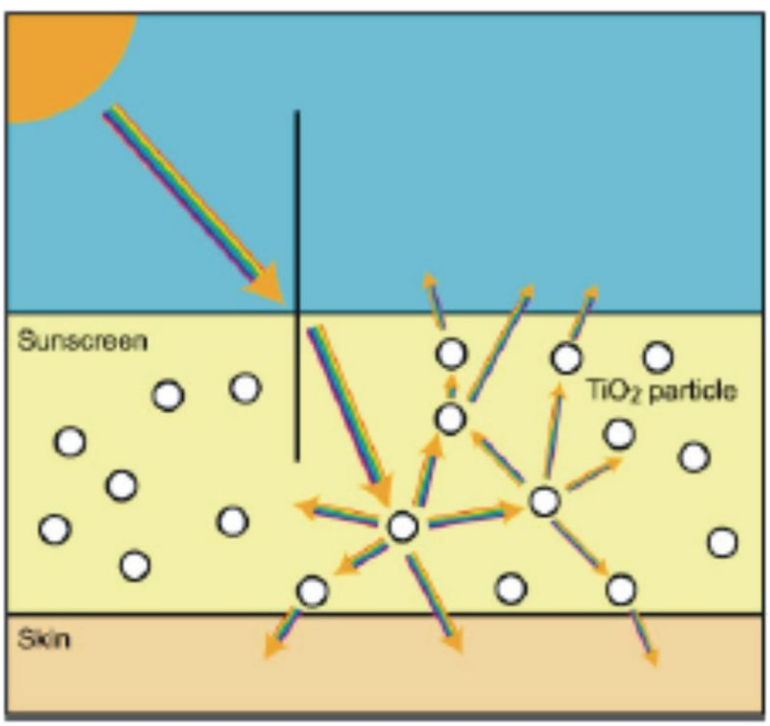


FIGURE 2.110

- ($>$ 200 nm)
- Large clusters can scatter light in many different directions
- Maximum scattering occurs for wavelengths twice as large as the cluster
  - $\lambda > 400$ nm
  - This is **visible** light!

Why Do They Appear White? II

Light eventually goes in one of two directions:

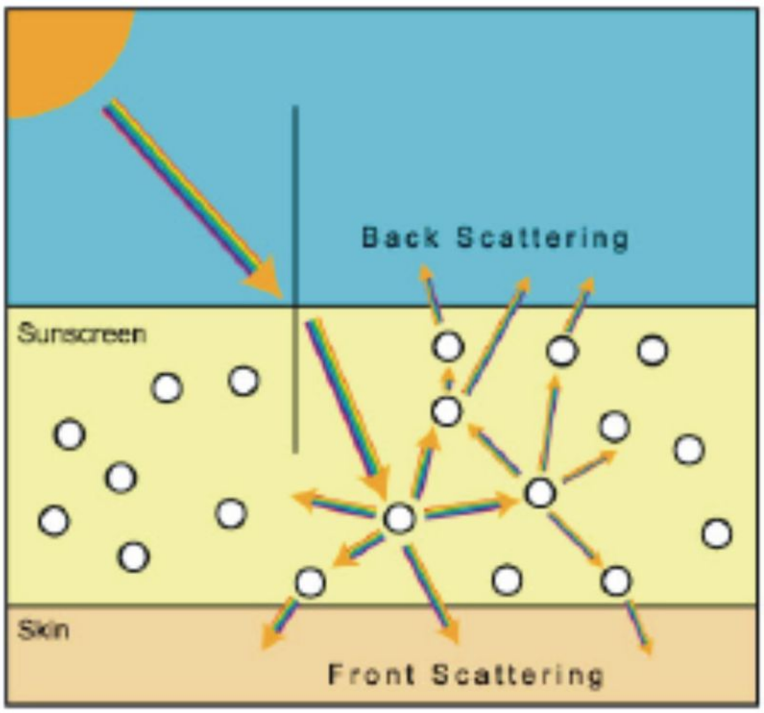


FIGURE 2.111

- Back the way it came (back scattering)
  - Back-scattered light is reflected
- Forwards in the same general direction it was moving (front scattering)
  - Front-scattered light is transmitted

Why Do They Appear White? III

- When reflected visible light of all colors reaches our eyes, the sunscreen appears white
- This is very different from what happens when sunlight is reflected off our skin directly
  - Green/blue rays absorbed
  - Only red/brown/yellow rays reflected

Why don't organic sunscreen ingredients scatter visible light?

Organic Sunscreen Molecules are Too Small to Scatter Visible Light

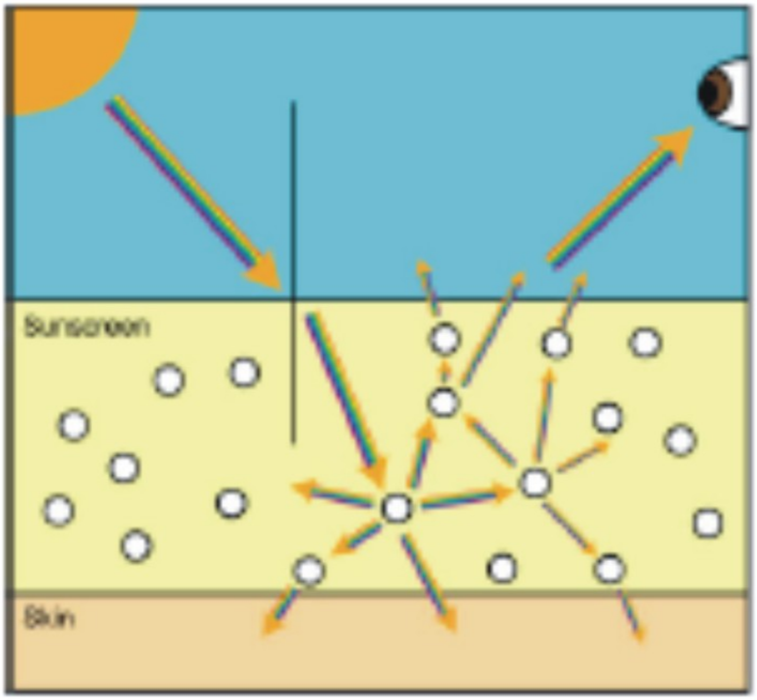


FIGURE 2.112

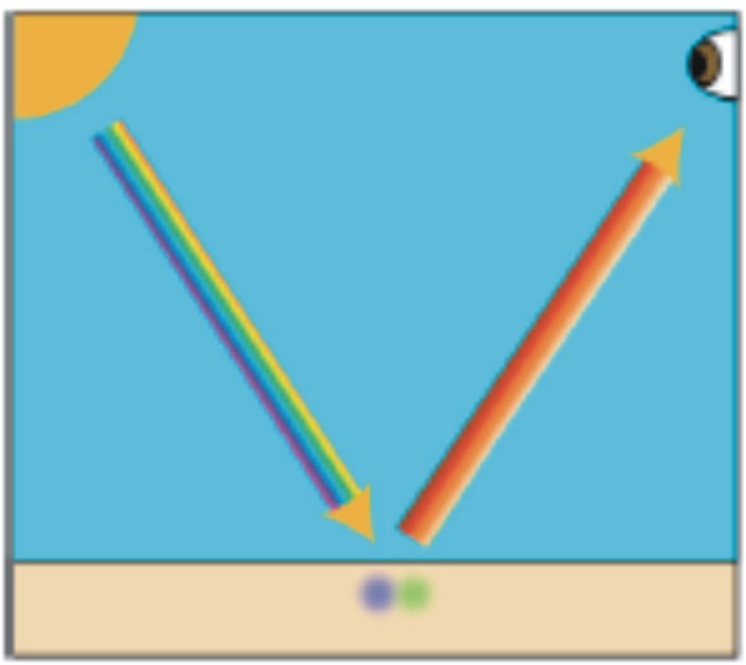


FIGURE 2.113

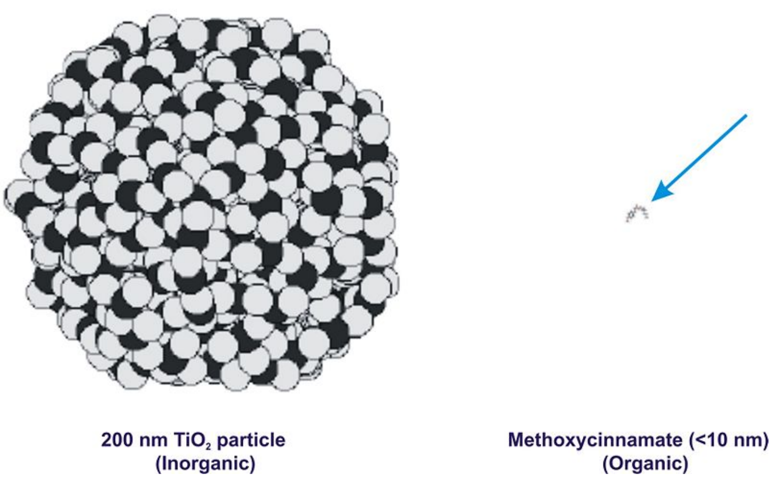


FIGURE 2.114

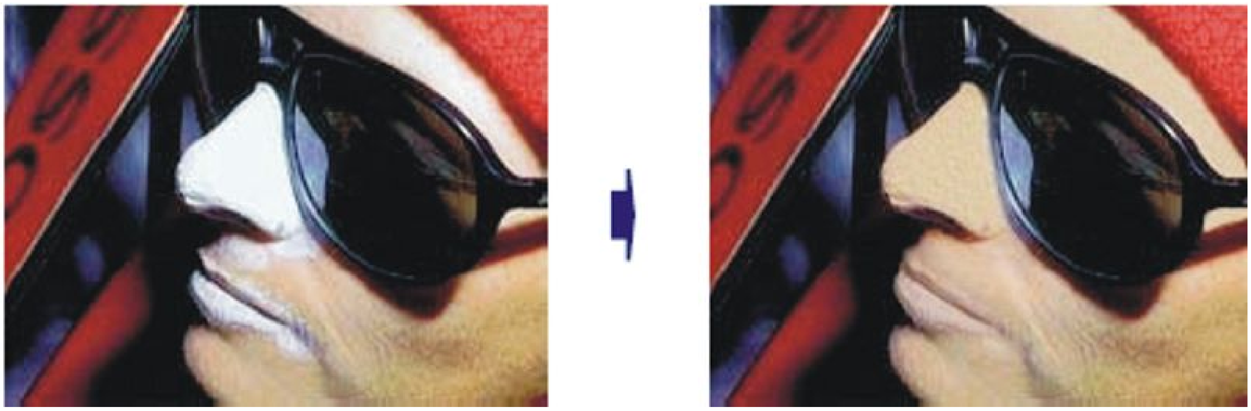


FIGURE 2.115

What could we do to inorganic clusters to prevent them from scattering visible light?

Nanosized Inorganic Clusters I

- Maximum scattering occurs for wavelengths twice as large as the clusters
  - Make the clusters smaller (100 nm or less) and they won't scatter visible light

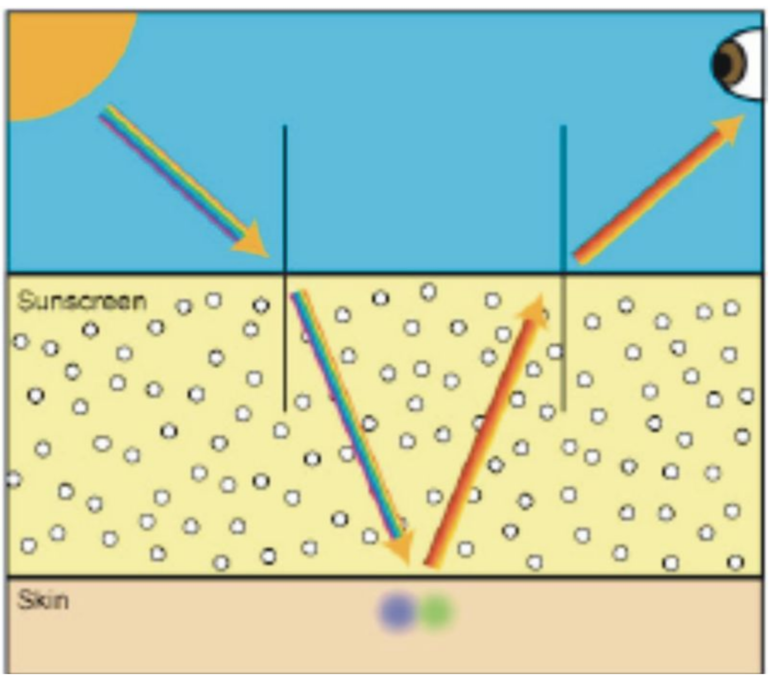


FIGURE 2.116

Nanosized Inorganic Clusters II

- Maximum scattering occurs for wavelengths twice as large as the clusters
  - Make the clusters smaller (100 nm or less) and they won't scatter visible light

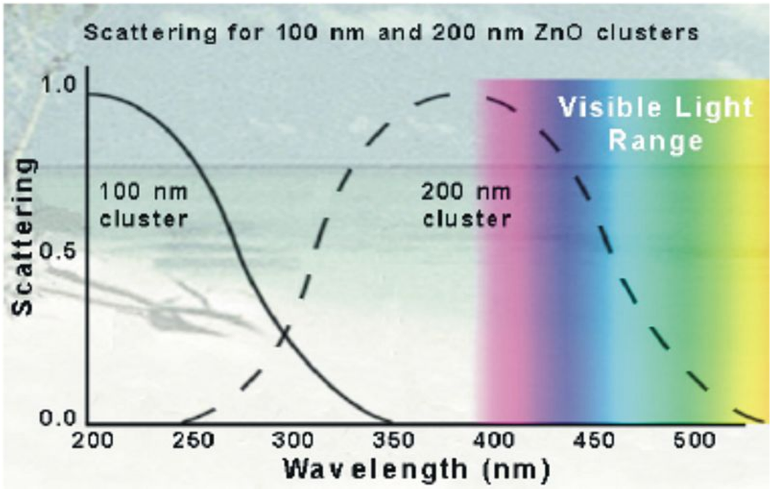


FIGURE 2.117

Nano-Sunscreen Appears Clear

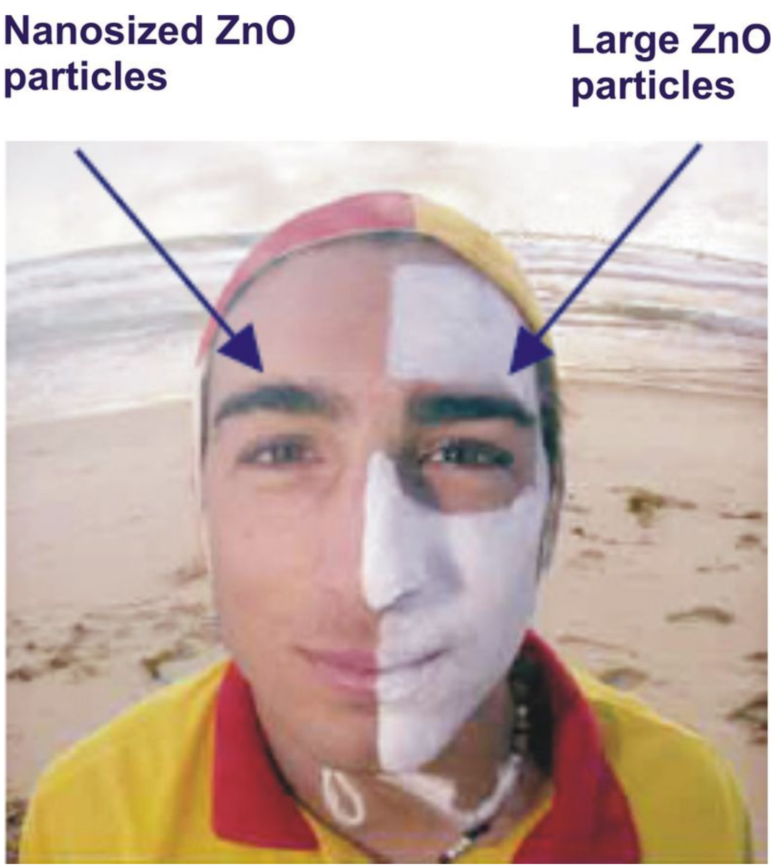


FIGURE 2.118

TABLE 2.44: In Summary I

	Organic Ingredients	Inorganic Ingredients (Nano)	Inorganic Ingredients (Large)
Structure	Individual molecule	Cluster ∼ 100 nm in diameter	Cluster > 200 nm in diameter
Interaction w/UV light	Absorb specific λ of UV light	Absorb all UV < critical λ	Absorb all UV < critical λ
Absorption Range	Parts of UVA or UVB spectrum	Broad spectrum, both UVA and UVB	Broad spectrum, both UVA and UVB
Interaction w/Vis light	None	None	Scattering
Appearance	Clear	Clear	White

In Summary II

- Nanoparticle sunscreen ingredients are small inorganic clusters that:
  - Provide good UV protection by absorbing most UVB and UVA light
  - Appear clear on our skin because they are too small to scatter visible light

FIGURE 2.119

NanoSunscreen: The Wave of the Future?: Teacher Notes

Overview

This series of interactive slides cover the basic science for how nanosunscreens work, including:

- The dangers of UV radiation and our need to protect ourselves against them

- The history of sunscreens and the different types available
- How sunscreens absorb UV light and what determines which wavelengths are absorbed
- How scattering of visible light by sunscreen determines if they appear white or clear

Slide 29 includes an optional demo that shows how selective absorption of UV light by certain chemicals used in printing money is serves as an anti-counterfeiting measure. If you choose to do this demo you will need:

- One or more UV lights of any size (several options are available from Educational Innovations at www.teachersource.com)
- Different kinds of paper currency (these must be relatively recently printed; Euros and Canadian bills work particularly well)

Slide 43 includes an optional animation to illustrate the process of how UV and visible light interacts with sunscreen and our skin. This animation can be downloaded from the NanoSense website at http://nanosense.org/activities/clearsunscreen/inc

Three Student Handouts are provided to support the concepts introduced in the PowerPoint. These can be given out at any point, but relevant slide suggestions are given:

- Sun Radiation Summary (Slides 16/17)
- Summary of FDA Approved Sunscreen Ingredients (Slide 30)
- Overview of Sunscreen Ingredients (Slide 26 or 46)

Slide 1: Title Slide

Questions for Students: Do you wear sunscreen? Why or why not? Are there nanoparticles in your sunscreen? How do you know?

Slide 2: Part 1 – Understanding the Danger (Section Header)

Slide 3: Why use sunscreen? (Question Slide)

Have your students brainstorm ideas about why it is important to use sunscreen.

Slide 4: Too Much Sun Exposure is Bad for Your Body

This slide describes the three main dangers of UV radiation:

- Premature skin aging leads to leathery skin, wrinkles and discolorations or "sun spots". Eyes can also be damaged by UV radiation leading to cataracts (damage to the eyes which causes cloudy vision).
- Sunburns are not only painful but are also a distress response of the skin giving us a signal that damage is being done.
- Skin cancer occurs when UV rays damage DNA in skin cells leading to genetic mutations. The mutated cells grow and divide uncontrollably forming a tumor. If caught early, the cancer can be removed; otherwise it can spread to other parts of the body and eventually cause death.

Slide 5: Skin Cancer Rates are Rising Fast

This slide describes the most dangerous consequence of UV radiation – skin cancer.

It is only recently that being tan came into fashion and that people began to spend time in the sun on purpose in order to tan. In addition, clothing today generally reveals more skin than it did in the past.

The use of tanning beds is not safe and a "base tan" only provides protection of about SPF 4.

Discussion Question for Students: Are there any other reasons that skin cancer rates might be rising?

Answer: Improvements in detection technology may mean that we identify more cases inflating the slope of the rise.

Slide 6: What are sun rays? How are they doing damage? (Question Slide)

Have your students brainstorm ideas about what sun rays are and how they interact with our body.

Slide 7: The Electromagnetic Spectrum

Note: The illustrations of the waveforms at the extremes of the wavelength/energy spectrum are not to scale. They are simply meant to be a graphical representation of longer and shorter wavelengths.

You may want to discuss some of the properties and uses of the different parts of the electromagnetic spectrum further with your students:

- Gamma rays result from nuclear reactions and have a very high frequency and energy per photon (very short wavelength). Because they have a high energy, the photons can penetrate into cell nuclei causing mutations in the DNA.
- $X-$ rays are produced in collision of high speed electrons and have a high frequency and energy per photon (short wavelength). Because they have a smaller energy than gamma rays, the $x-$ ray photons can pass through human soft tissue (skin and muscles) but not bones.
- Ultra Violet Light is produced by the sun and has a somewhat high frequency and energy per photon (somewhat short wavelength). Different frequencies of UV light (UVA, UVB) are able to penetrate to different depths of human skin.
- Visible Light is produced by the sun (and light bulbs) and has a medium frequency and energy per photon (medium wavelength). Visible light doesn't penetrate our skin, however our eyes have special receptors that detect different intensities (brightnesses) and frequencies (colors) of light (how we see).
- Infrared Light is emitted by hot objects (including our bodies) and have a low frequency and energy per photon (long wavelength). Infrared waves give our bodies the sensation of heat (for example when you stand near a fire or out in the sun on a hot day.)
- Radio Waves are generated by running an alternating current through an antenna and have a very low frequency and energy per photon (very long wavelength). Because they are of such low energy per photon, they can pass through our bodies without interacting with our cells or causing damage.

Slide 8: The Sun's Radiation Spectrum I

Sun rays are a form of electromagnetic radiation. Electromagnetic radiation is waves of oscillating electric and magnetic fields that move energy through space.

Discussion Question for Students: What is the difference between UVA, UVB and UVC light?

Answer: They have different wavelengths, frequencies (UVC: $\sim 100-280$ nm ; UVB: $\sim 280-315$ nm ; UVC $\sim 315-400$ nm) and thus different energies.

Note: The division of the UV spectrum (as well as the division of UV, visible, infrared etc.) is a categorization imposed by scientists to help us think about the different parts of the electromagnetic spectrum, which is actually a continuum varying in wavelength and frequency.

Slide 9: The Sun's Radiation Spectrum II

The sun emits primarily UV, visible and IR radiation. $< 1\%$ of the sun's radiation is $x-$ rays, gamma waves, and radio waves.

The amount of each kind of light emitted by the sun is determined by the kinds of chemical reactions occurring at the sun's surface.

You may want to point out to students that not all of the sun's radiation reaches the earth.

There are several layers of gases surrounding the earth, called its atmosphere, which absorb some of this radiation

- Water vapor (H_2O) absorbs IR rays
- Ozone (O_3) absorbs some UV rays
- Visible rays just pass through

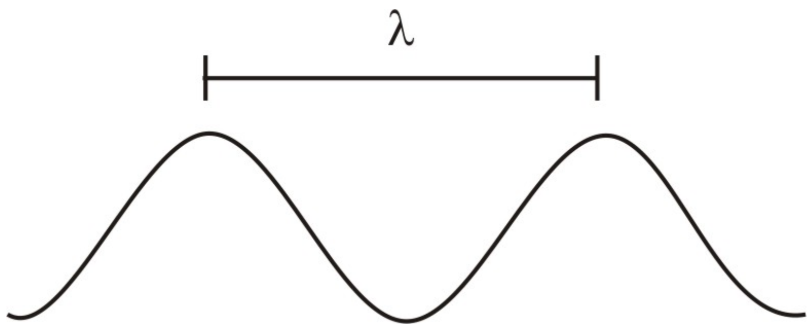
As the ozone layer is depleted, more of the UV light emitted by the sun will reach the earth.

Slide 10: How can the sun's rays harm us? (Question Slide)

Have your students brainstorm ideas about how sun rays might interact with our body. What part(s) of our body do they interact with? How do they affect them?

Slide 11: Sun Rays are Radiation

If students are not already familiar with the concept of wavelength, it may help to draw a wave on the board and indicate that the wavelength is the distance between peaks.



The speed of light in a vacuum is always the same for all wavelengths and frequencies of light. $(c = 300,000,000 \text{ m/s})$

You may wish to point out to students that the letter ' c ' is the same c in the famous $E = mc^2$ equation showing the relationship between matter and energy.

You may also want to discuss the concept that all light travels at the same speed in the same medium and that this does not depend on the frequency or wavelength of the wave. For example, in other mediums (e.g. air, water) light travels slower than in a vacuum. The speed of all light in water is $\sim 225,563,909 \text{ m/s}$ (only 75% of speed in a vacuum.)

Slide 12: Radiation Energy I

Example: Imagine that you are outside your friend's window trying to get their attention. You can throw small pebbles at the window one after another for an hour and it won't break the window. On the other hand, if you throw a big rock just once, you will break the window. It doesn't matter if all the pebbles put together would be bigger and heavier than the one rock; because their energy is delivered as separate little packets, they don't do as much damage. The same is true with energy packets.

h is Planck's constant $(6.26 \times 10^{-34} \text{ J s})$

Slide 13: Radiation Energy II

Total Energy can not be predicted by the frequency of light.

You may want to talk with your students about the different things that the total energy depends upon. For example: time of day (10am-2pm is the most direct and strongest sunlight), time of year, amount of cloud cover (though some UV always gets through), altitude.

You may want to explore the UV index site with your students and look at how the index varies by location.

Slide 14: Skin Damage I

Discussion Question for Students: Which kinds(s) of UV light do you think we are most concerned about and why?

Answer: The theoretical answer would be UVC#62;UVB#62;UVA in terms of concern because of energy packet size. This is true for acute (immediate) damage, though as shown in next slide, UVA has now been found to cause damage in the long term. UVC is currently not a major concern because it is absorbed by the atmosphere and thus doesn't reach our skin.

Slide 15: Skin Damage II

Premature aging is caused by damage to the elastic fibers (collagen) in the dermal layer of the skin. Because UVA radiation has a lower frequency and thus lower energy per photon, it is not absorbed by the cells of the top layer of the skin (the epidermis) and can penetrate deeper into the skin (to the dermis) where it does this damage.

Both UVA and UVB can enter the cell nucleus and cause mutations in the DNA leading to skin cancer.

Most of the rapid skin regeneration occurs in the epidermal layer. The dermal layer does not regenerate as quickly and thus is subject to long term damage.

Slide 16: Sun Radiation Summary I

This slide and the following one sum up the differences between the different kinds of radiation emitted by the sun. There is a corresponding student handout that students can use as a quick reminder during the course of the unit.

This graph contains the all the information about wavelength, frequency, energy and amount of each kind of radiation emitted by the sun. Note that the different "kinds" of radiation are really points on a continuum.

Common Misconception: We see "black light" (UVA light) because it is close to the visible spectrum.

The Real Deal: If that were true, we would be able to see all objects as bright under black light and that doesn't happen. For example at a party only certain clothes appear bright. What actually happens is that black light causes some materials to fluoresce or phosphoresce meaning they absorb the UVA light and re-emit violet light in the visible spectrum that our eyes can detect.

Slide 17: Sun Radiation Summary II

This slide and the previous one sum up the differences between the different kinds of radiation emitted by the sun. There is a corresponding student handout that students can use as a quick reminder during the course of the unit.

This chart summarizes the all the information from the previous graph and lists the effects of each kind of radiation on the human body.

Note: Different diagrams may have different cutoffs for the divisions between UVA, UVB, UVC, visible and IR. This is because the electromagnetic spectrum is a continuum and the divisions between categories are imposed by scientists, thus not always well agreed upon.

Example: What determines if it is a "warm" versus a "hot" day? If you set the cutoff at 80 degrees Fahrenheit does that mean that a change from $79°F$ to $81°F$ is more meaningful than a change from $77°F$ to $79°F$?

Slide 18: Part 2 – Protecting Ourselves (Section Header)

Slide 19: What do Sunscreens Do?

This slide is designed to get students thinking about how sunscreens protect our skin. Have students brainstorm ideas about what might happen to the UV rays when they encounter the sunscreen. Ask them how they could test their ideas to see if they are correct.

Slide 20: Light Blocking

The $T+R+A = 100\%$ equation is based on the conservation of energy. All incoming light (energy) must be accounted for. It either passes through the material, is sent back in the direction from which it came or is absorbed by the material.

Analogy: The $R+T+A = 100\%$ equation can be thought of in terms of baseball. When a pitcher throws the ball towards the batter, three things can happen. The batter can hit the ball (reflection), the catcher can catch the ball (absorption), or the ball can pass by both of them (transmission).

A key point on this slide is that sunscreens block UV light by absorbing it.

Slide 21: A Brief History of Sunscreens: The Beginning

Sunscreens were developed to meet a specific and concrete need: prevent soldiers from burning when spending long hours in the sun. Scientists applied their knowledge of how light interacts with certain chemicals to develop products to meet this need.

The division of the continuous UV spectrum into UVA and UVB categories is somewhat arbitrary. The UVB range is talked about as starting at around $280 - 290$ nm at the lower end and ending around $310 - 320$ nm at the upper end.

Slide 22: A Brief History of Sunscreens: The SPF Rating

SPF (Sunscreen Protection Factor) values are based on an "in-vivo" test (done on human volunteers) that measures the redness of sunscreen-applied skin after a certain amount of sun exposure.

SPF used to be thought of a multiplier that can be applied to the time taken to burn, but this is not done anymore because there are so many individual differences and other variables that change this equation (skin type, time of day, amount applied, environment, etc.)

The FDA recommends always using sunscreens with an SPF of at least 15 and not using sunscreen as a reason to stay out in the sun longer. Remind students that no sunscreen can prevent all possible skin damage.

Common Student Question: Is it true that sunscreens above SPF 30 don't provide any extra protection?

Answer: No, this is not true. However, since SPF is not based on a linear scale, a sunscreen with an SPF of 40 does not provide twice as much protection as a sunscreen with an SPF of 20 . Even though you don't get double the protection, you do get some additional protection and so there is added value in using SPFs above 30 .

In the past the FDA only certified SPFs up to 30 but didn't confirm the reliability of higher claims by sunscreen manufacturers. Recently, due to improvement in testing procedures, the FDA had proposed certifying results up to and SPF of 50 .

Slide 23: A Brief History of Sunscreens: The UVA Problem

Since there is no immediate visible effect, it is relatively recently that we have come to understand the dangers of UVA rays. In August 2007, the FDA proposed a UVA rating to be included on sunscreen labels; as of December 2007, the proposal was still under discussion. If the FDA proposal is passed, sunscreen manufacturers will have 18 months to comply with the new labeling requirements.

Creating a rating for UVA protection has been difficult for two reasons:

1. Since UVA radiation does not lead to immediate visible changes in the skin (such as redness) what should be the outcome measure? Is it valid to do an "in-vitro" (in a lab and not on a human) test? (*The FDA proposal includes both*)
2. How should the UVA protection level be communicated to consumers without creating confusion (with the SPF and how to compare / balance the two ratings)? (*The FDA proposal uses a* $4-$ *star system*)

Creating a UVA blocking rating is important since without immediate harmful effects, people are not likely to realize that they have not been using enough protection until serious long term harm has occurred.

Slide 24: How do you know if your sunscreen is a good UVA blocker? (Question Slide)

Have your students brainstorm ideas about ways to tell if a sunscreen is a good UVA blocker.

Slide 25: Know Your Sunscreen: Look at the Ingredients

"Formulating" a sunscreen is the art of combing active and inactive ingredients together into a stable cream or gel product. One of the important challenges here is creating a stable suspension with even ingredient distribution. If the active ingredients clump together in large groups then the sunscreen provides strong protection in some areas and little protection in others.

Analogy: Students may be familiar with the suspension issue as it relates to paint. If paint has been sitting for a while and it is used directly, a very uneven color is produced. This is why we stir (or shake) paint before using in order to re-suspend the particles.

Another issue in sunscreen formulation is trying to create a product that customers will want to buy and use. Qualities such as smell, consistency and ease of rubbing into the skin all play a role in whether or not a sunscreen will be used and whether it will be used in sufficient quantity.

Slide 26: Sunscreen Ingredients Overview

This slide is an advance organizer for the content of the rest of the slide set. You may wish to give your students the Overview of Sunscreen Ingredients: Student Handout at this point to refer to during the rest of the presentation.

You do not need to discuss the details of each cell at this point in the presentation, simply point out that organic and inorganic ingredients have several different properties that will be discussed. All of the content of the table is explained in detail in the following slides.

Slide 27: Organic Ingredients: The Basics

The full name of the compound shown is octyl methoxycinnamate (octyl refer to the eight carbon hydrocarbon tail shown on the right side of the molecule) but it is commonly referred to as octinoxate or OMC.

Slide 28: Organic Ingredients: UV Blocking

When a molecule absorbs light, energy is converted from an electromagnetic form to a mechanical one (in the form of molecular vibrations and rotations). Because of the relationship between molecular motion and heat, this is often referred to as thermal energy.

The process of releasing the absorbed energy is called relaxation. While atoms which have absorbed light simply re-emit light of the same wavelength/energy, molecules have multiple pathways available for releasing the energy. Because of the many vibrational and rotational modes available, there are many choices for how to relax. Since these require smaller energy transitions than releasing the energy all at once, they provide an easier pathway for relaxation – this is why the energy absorbed from the UV light is released as harmless (low energy) IR radiation.

Slide 29: Organic Ingredients: Absorption Range

Light absorption by molecules is similar to the emission of light by atoms with three key differences:

- Light is captured instead of released.
- Molecules absorb broader bands of wavelengths than atoms because there are multiple vibrational and rotational modes to which they can transition (for more details on molecular absorption concepts, see the Lesson 3 PPT and teacher notes).
- There are multiple pathways for relaxation – the light emitted does not have to be the same wavelength as the light absorbed.

Different molecules have different peak absorption wavelengths, different ranges of absorption and differences in how quickly absorption drops off ("fat" curves as compared to "skinny" ones). It is important to realize that even within a molecule's absorption range, it does not absorb evenly and absorption at the ends of the range is usually low. For example, octyl methoxycinnamate has an absorption range of 295 – 350 nm , but we would not expect it to be a strong absorber of light with a wavelength of 295 nm .

UV Absorption Demonstration: As one effort to prevent the circulation of counterfeit currency, bills are often printed with special chemicals that absorb specific wavelengths of UV light (this occurs because the energy of these UV rays matches the difference between the molecule's energy levels). When one of these bills is held under a UV light, these molecules absorb the UV light and reemit purple light in the visible spectrum that we can see (note that that the remitted light is <u>not</u> UV light which is not visible to the human eye). You can demonstrate this effect for your students by turning off the classroom lights and shining a UV light on different kinds of bills and watching the printed designs appear (these must be relatively recently printed; Euros and Canadian bills have particularly interesting designs). If you have two UV lights of different wavelengths, you may even be able to see two different designs due to the selective absorption of the different molecules used in the printing.

Slide 30: Organic Ingredients: Absorbing UVA / UVB

Many organic ingredients block "shortwave" UVA light (also called UVA 2 light and ranging from ~ 320 to $340\ nm$) but not "longwave" UVA light (also called UVA 1 light and ranging from ~ 340 to $400\ nm$). Up till 2006, avobenzone was the only organic ingredient currently approved by the FDA that is a good blocker of longwave UVA light.

This is a good point to give you students the Summary of FDA Approved Sunscreen Ingredients: Student Handout. Have students look at the different kind of molecules and compounds and see what kind of wavelengths are protected against by which ingredient.

Slide 31: How are inorganic sunscreen ingredients different from organic ones? How might this affect the way they block UV light? (Question Slide)

Have your students brainstorm how inorganic sunscreens might be different from organic ones and how this might affect the way they block UV light.

Slide 32: Inorganic Ingredients: The Basics

Inorganic compounds are described by a formula unit instead of a molecular formula. The big difference is that while a molecular formula tells you exactly how many of each kind of atom are bonded together in a molecule; the formula unit only tells you the ratio between the atoms. Thus while all molecules of an organic substance will have exactly the same number of atoms involved (and thus be the same size), inorganic clusters can be of any size as long as they have the correct ratio between atoms. This occurs because inorganic substances are held together by ionic, not covalent bonds.

You may want to review some of the basics of bonding in inorganic compounds (electrostatic attraction between ions) as opposed to bonding in organic molecules (electron sharing via covalent bonds) with your students here.

Slide 33: Inorganic Ingredients: Cluster Size

Note: the proper scientific name for TiO_2 is "titanium (IV) oxide", but the older name "titanium dioxide" is more commonly used.

This slide is a re-emphasizes the difference between a molecular formula and the formula unit of an inorganic substance. While the molecular formula indicates the actual number of atoms that combine together to form a molecule, the formula unit indicates the ratio of atoms that combine together to form an inorganic compound. Molecules are always the same size whereas inorganic compounds can vary in the number of atoms involved and thus the size of the cluster.

Common Confusion: Inorganic compound clusters are often referred to informally as "particles". Students often confuse this use of the word particle with the reference to the sub-atomic particles (proton, electrons and neutrons) or with reference to a molecule being an example of a particle.

Slide 34: Inorganic Ingredients: UV Blocking

When an inorganic compound absorbs light, energy is converted from an electromagnetic form to a mechanical one (kinetic energy of electrons). The excited electrons use this kinetic energy to "escape" the attraction of the positively charged nuclei and roam more freely around the cluster.

Because there are so many more atoms involved in an inorganic compound than in a molecule, there are also many more different energy values that electrons can have (students can think of these loosely as how "free" the electrons are to move about the cluster; how far from their original position they can roam). The greater number of possible energy states means that a greater range of wavelengths of UV light can be absorbed leading to the broader absorption spectrum shown in the graph.

Slide 35: If inorganic sunscreens ingredients block UVA light so well, why doesn't everybody use them? (Question Slide)

Have your students brainstorm reasons why sunscreen manufacturers and consumers might not want to use inorganic sunscreen ingredients.

Slide 36: Appearance Matters

One of the major reasons that people have not used inorganic ingredients in the past is because of their appearance. Before we knew how dangerous UVA rays were, sunscreens with organic ingredients seemed to be doing a good job (since they do block UVB rays).

Applying too little sunscreen is very dangerous because this reduces a sunscreen's blocking ability while still giving you the impression that you are protected. In this situation people are more likely to stay out in the sun longer and then get burned.

Slide 37: Why Do They Appear White? I

Scattering is a physical process that depends on cluster size, the index of refraction of the cluster substance and the index of refraction of the suspension medium. No energy transformations occur during scattering (like they do in absorption); energy is simply redirected in multiple directions. The wavelengths (and energy) of light coming in and going out are always the same.

Maximum scattering occurs when the wavelength is twice as large as the cluster size. Since traditional inorganic sunscreen ingredients have diameter > 200 nm , they scatter light which is > 400 nm in diameter – this is in the visible spectrum.

Slide 38: Why Do They Appear White? II

Multiple scattering is a phenomenon of colloids (suspended clusters). When light is scattered, at the micro level it goes in many directions. At the macro level, it eventually either goes back the way it came or forwards in the same general direction it was moving. These are known as back- and front- scattering and they contribute to reflection and transmission respectively.

Note that the formula presented earlier (Reflection $+$ Transmission $+$ Absorption $= 100\%$) still holds. Scattering simply contributes to the "reflection" and "transmission" parts of the equation. (For more details on scattering concepts, see the Lesson 4 PPT and teacher notes).

Slide 39: Why Do They Appear White? III

The scattering of visible light by ZnO and TiO_2 is the cause of the thick white color seen in older sunscreens. When the different colors of visible light are scattered up and away by the sunscreen, they reach our eyes. Since the combination of the visible spectrum appears white to our eyes, the sunscreen appears white.

Depending on your students' backgrounds, you may want to review how white light is a combination of all colors of light.

You may also want to discuss how the pigment in our skin selectively absorbs some colors (wavelengths) of visible light, while reflecting others. This is what usually gives our skin its characteristics color. Different pigments (molecules) absorb different wavelengths; this is why different people have different color skin.

Slide 40: Why don't organic sunscreen ingredients scatter visible light? (Question Slide)

Have your students brainstorm reasons why organic sunscreen ingredients don't scatter visible light.

Slide 41: Organic Sunscreen Molecules are Too Small to Scatter Visible Light

Traditional inorganic clusters are usually 200 nm or larger, causing scattering in the visible range ($400-700$ nm) . Organic sunscreen molecules are smaller than 10 nm (usually $1-20$ Angstroms) and thus do not scatter in the visible range.

You may want to talk about how while the individual organic sunscreen molecules are very small compared to inorganic sunscreen clusters (many formula units ionically bonded together creating a large cluster) and the wavelengths of visible light, they are big compared to many of the simple molecules that students are used to studying, such as water or hydrochloric acid.

How big or small something seems is relative to what you are comparing it to. In this case, we are comparing sunscreen ingredients with the size of the wavelength of light.

Slide 42: What could we do to inorganic clusters to prevent them from scattering visible light? (Question

Slide)

Have your students brainstorm what we could do to inorganic clusters to prevent them from scattering light. If students say "make them smaller", ask them how small the clusters would need to be in order to not scatter visible light.

Slide 43: Nanosized Inorganic Clusters I

When visible light is not scattered by the clusters, it passes through the sunscreen and is reflected by our skin (blue and green rays are absorbed by pigments in the skin and the red, yellow and orange rays are reflected to our eyes giving skin its characteristic color).

Optional Animation: If you have time, you may want to demo the sunscreen animations for your class at this point. The animations are available at http://nanosense.org/activities/clearsunscreen/index.html and are explained in the Sunscreens #38; Sunlight Animations: Teacher Instructions #38; Answer Key in Lesson 4.

Slide 44: Nanosized Inorganic Clusters II

As the graph shows, 200 nm clusters scatter significant portions of the visible spectrum, while 100 nm clusters do not.

Changing the size of the cluster does not affect absorption since this depends on the energy levels in the substance which are primarily determined by the substance's chemical identity.

Discussion Question for Students: Is it good or necessary to block visible light from reaching our skin?

Answer: Visible light has less energy than UVA light and is not currently thought to do any harm to our skin thus there is no need to block it. Think about human vision: visible light directly enters our eyes on a regular basis without causing any harm.

Slide 45: Nano-Sunscreen Appears Clear

This slide shows the difference in appearance between traditional inorganic and nanosunscreens.

Slide 46: In Summary I

If you have not yet given your students the Overview of Sunscreen Ingredients: Student Handout, do so now. Use the handout to review the similarities and differences between the three kinds of ingredients.

Key Similarities #38; Differences:

- Both kinds of inorganic ingredients have the same atoms, structure and UV absorption
- Nano-inorganic clusters are much smaller than the cluster size of traditional inorganic ingredients, thus do not scatter visible light, thus are clear.

Slide 47: In Summary II

The big benefit of nano-sunscreen ingredients is that they combine UVA blocking power with an acceptable appearance.

CHAPTER 3 Fine Filters-Teacher Materials

CHAPTER OUTLINE

3.1 FILTERING SOLUTIONS FOR CLEAN WATER

3.1 Filtering Solutions for Clean Water

Unit Overview

Contents

- For Anyone Planning to Teach Nanoscience... Read This First!
- Fine Filters Overview, Learning Goals #38; Standards
- Unit at a Glance: Suggested Sequencing of Activities
- Alignment of Unit Activities with Learning Goals
- Alignment of Unit Activities with Curriculum Topics
- (Optional) Fine Filters Pretest/Posttest: Teacher Answer Sheet

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 #38; 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 #38; 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., #38; Robbins, M. (2005, June). The breakdown of continuum models for mechanical contacts. *Nature 435,* 929-932.

TABLE 3.1: 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

Fine Filters: Overview, Learning Goals #38; Standards

Type of Courses: Chemistry

Grade Levels: 9-12

Topic Area: Separation of solutions

Key Words: Nanoscience, nanotechnology, separation of mixtures, filtration, nanofiltration, solutions, water

Time Frame: 4 class periods (assuming 50 − minutes classes), with extensions available

Overview

The shortage of clean drinking water is a pressing global issue. In the twentieth century, demand for water increased six fold, more than double the rate of growth of the human population. At the same time, pollution and over-extraction of water in many regions of the world has reduced the ability of supplies to meet the demand. The United

Nations estimates that over a billion people lack access to safe drinking water.

Part of the solution to the water crisis comes from filtration technologies that make water clean enough to drink. For water that contains salt, (97% of earth's water), reverse osmosis is now in use for removing sodium ions. Reverse osmosis is an expensive process, because it requires high pressure—and hence more energy in the form of electricity—to force the affluent (impure water) through the filter membrane.

For water that does not contain salt, a new and more cost-effective technology— nanofiltration—is just beginning to be used. Nanofiltration can remove minerals, sugars, and color from water, and costs much less than reverse osmosis because the process requires much less pressure. There are a multitude of research efforts to develop nanomembranes for water filtration. Researchers anticipate that several forms of this new technology will be available in the next few years. This new generation of membranes is designed to be equally effective as currently used purification treatments, but significantly less expensive so that poor communities can afford clean drinking water.

Enduring Understandings (EU)

What enduring understandings are desired? Students will understand:

1. A shortage of clean drinking water is one of the most pressing global issues.
2. As a result of water's bent shape and polarity, water has unique properties, such as an ability to dissolve most substances. These properties are responsible for many important characteristics of nature.
3. Pollutants can be separated from water using a variety of filtration methods. The smaller the particle that is to be separated from a solution, the smaller the required pore size of the filter and the higher the cost of the process.
4. Innovations using nanotechnology to create a new generation of membranes for water filtration are designed to solve some critical problems in a cost-effective way that allows for widespread use.

Essential Questions (EQ)

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

1. Why are water's unique properties so important for life as we know it?
2. How do we make water safe to drink?
3. How can nanotechnology help provide unique solutions to the water shortage?
4. Can we solve our global water shortage problems? Why or why not?

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 the global distribution of clean drinking water and explain some of the causes and consequences of water scarcity.
2. Describe different types of filtration in terms of the pore size of the filter, substances it can separate, and cost of use.
3. Use laboratory procedures to compare the relative effectiveness of different filtration methods on particle separation.
4. Describe the basic structure and charge distribution of water.
5. Explain how hydrogen bonding accounts for many of water's unique properties.

Prerequisite Knowledge

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

1. Atoms, molecules, ions.
2. Homogeneous and heterogeneous solutions.

3. Solute-solvent interaction between ionic and molecular solutes and water.

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: (1 of the 5 categories apply)

- Form and function

Grades 9-12 Content Standard A: Scientific Inquiry

Abilities Necessary to Do Scientific Inquiry

- **Design and conduct scientific investigations**. Designing and conducting a scientific investigation requires introduction to the major concepts in the area being investigated, proper equipment, safety precautions, assistance with methodological problems, recommendations for use of technologies, clarification of ideas that guide the inquiry, and scientific knowledge obtained from sources other than the actual investigation. The investigation may also require student clarification of the question, method, controls, and variables; student organization and display of data; student revision of methods and explanations; and a public presentation of the results with a critical response from peers. Regardless of the scientific investigation performed, students must use evidence, apply logic, and construct an argument for their proposed explanations. (12ASI1.2)
- **Formulate scientific explanations and models.** Student inquiries should culminate in formulating an explanation or model. Models should be physical, conceptual, and mathematical. In the process of answering the questions, the students should engage in discussions and arguments that result in the revision of their explanations. These discussions should be based on scientific knowledge, the use of logic, and evidence from their investigation. (12ASI1.4)
- **Communicate and defend a scientific argument**. Students in school science programs should develop the abilities associated with accurate and effective communication. These include writing and following procedures, expressing concepts, reviewing information, summarizing data, using language appropriately, developing diagrams and charts, explaining statistical analysis, speaking clearly and logically, constructing a reasoned argument, and responding appropriately to critical comments. (12ASI1.6)

Grades 9-12 Content Standard B: Physical Science

Structure and Properties of Matter

Compounds. The physical properties of compounds reflect the nature of the interactions among its molecules. These interactions are determined by the structure of the molecule, including the constituent atoms and the distances and angles between them. (12BPS2.4)

Grades 9-12 Content Standard E: Science and Technology

Abilities of Technological Design

- **Propose designs and choose between alternative solutions**. Students should demonstrate thoughtful planning for a piece of technology or technique. Students should be introduced to the roles of models and simulations in these processes. (12EST1.2)
- **Communicate the problem, process, and solution**. Students should present their results to students, teachers, and other in a variety of ways, such as orally, in writing, and in other forms—including models, diagrams, and demonstrations. (12EST1.5)

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

Personal and Community Health

- **Selection of foods and eating patterns determine nutritional balance**. Nutritional balance has a direct effect on growth and development and personal well-being. Personal and social factors—such as habits, family income, ethnic-heritage, body-size, advertising, and peer pressure—influence nutritional choices. (12FSPSP1.5)

Population Growth

- **Populations can reach limits to growth**. Carrying capacity is the maximum number of individuals that can be supported in a given environment. The limitation is not the availability of space, but the number of people in relation to resources and the capacity of earth systems to support human beings. Changes in technology can cause significant changes, either positive or negative, in carrying capacity. (12FSPSP2.1)

Natural Resources

- **Human populations use resources in the environment in order to maintain and improve their existence**. Natural resources have been and will continue to be used to maintain human populations. (12FSPSP3.1)
- **The earth does not have infinite resources**; increasing human consumption places severe stress on the natural processes that renew some resources, and it depletes those resources that cannot be renewed. (12FSPSP3.2)

Environmental Quality

- **Many factors influence environmental quality**. Factors that students might investigate include population growth, resource use, population distribution, overconsumption, the capacity of technology to solve problems, poverty, the role of economic, political, and religious views, and different ways humans view the earth. (12FSPSP4.3)

Science and Technology in Local, National, and Global Challenges

- **Science and technology are essential social enterprises**, but alone they can only indicate what can happen, not what should happen. The latter involves human decisions about the use of knowledge. (12FSPSP6.1)
- **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)

Unit at a Glance: Suggested Sequencing of Activities

Overview

The Fine Filters Unit has been designed in a modular fashion to allow you maximum flexibility in adapting it to your student's needs. Lesson 1 provides an introduction to the context and human need for clean drinking water. Combined with Lesson 3 (Nanofiltration), they make up the basic sequence for the unit. Lesson 2 is an extension that reviews some of the science basics of water. In particular, it reviews the structure of water and its unique properties based on the quantum mechanical model of the atom, the shape of the water molecule and the distribution of charge.

TABLE 3.2:

Lesson	Basic Sequence	Optional Extensions
Lesson 1: The Water Crisis	√	
Lesson 2: The Science of Water		√
Lesson 3: Nanofiltration	√	

Most lessons contain an interactive presentation and one or more options for activities so you can tailor the depth and duration of the lesson to meet your needs. The following pages contain a suggested sequencing of activities for the unit, but of course there are other combinations possible.

Suggested Sequencing of Activities for Unit

TABLE 3.3:

Lesson	Teaching Days	Main Activities and Materials	Learning Goals	Assessment	Homework
Lesson 1:	2 days: *Day 1*	The Water Crisis: PowerPoint and Discussion Initial Ideas: Student Worksheet	EU:1 KKS:1	Initial Ideas Worksheet	Student Data Worksheet
	Day 2 (10 min *only for quiz*)	Take and review quiz		Water Crisis Quiz	
Lesson 2: The Science of Water	3 days: *Day 1*	Science of Water PowerPoint and Discussion	EU: 2 KKS: 3, 4		Read Science of Water Lab Activity and generate hypotheses
(Optional)	*Day 2*	Science of Water Lab Activities		Reflection on Guiding Questions	Reflection on Guiding Questions
	Day 3 (35 min)	Reflection on Guiding Questions Take and review quiz		Science of Water Quiz	
Lesson 3: Nanofiltration:	3 days: *Day 1*	Nanofiltration: PowerPoint and Discussion Which Method is Best Activity	EU:3,4 KKS:2,3	Which Method is Best Worksheet	Nanofiltration: Student Reading Read Filtration Lab and generate hypotheses
	Day 2	Comparing Nanofilters to Conventional Filters Lab Activity		Filtration Lab Activity Worksheet	New Nano-Membranes Student Reading
	Day 3	Cleaning Jarny's Water Discuss Nano-Membranes Reading Discussion of Reflection on Guiding Questions		Jarny Student Report Final Reflections	

Table 3.4:

What **enduring understandings (EU)** are desired? Students will understand:	What **essential questions (EQ)** will guide this unit and focus teaching and learning?	What **key knowledge and skills (KKS)** will students acquire as a result of this unit? Students will be able to:
1. A shortage of clean drinking water is one of the most pressing global issues. 2. As a result of water's bent shape and polarity, water has unique properties, such as an ability to dissolve most substances. These properties are responsible for many important characteristics of nature. 3. Pollutants can be separated from water using a variety of filtration methods. The smaller the particle that is to be separated from a solution, the smaller the required pore size of the filter and the higher the cost of the process. 4. Innovations using nanotechnology to create a new generation of membranes for water filtration are designed to solve some critical problems in a cost effective way that allows for widespread use.	1. Why are water's unique properties so important for life as we know it? 2. How do we make water safe to drink? 3. How can nanotechnology help provide unique solutions to the water shortage? 4. Can we solve our global water shortage problems? Why or why not	1. Describe the global distribution of clean drinking water and explain some of the causes and consequences of water scarcity. 2. Describe different types of filtration in terms of the pore size of the filter, substances it can separate, and cost of use. 3. Use laboratory procedures to compare the relative effectiveness of different filtration methods on particle separation. 4. Describe the basic structure and charge distribution of water. 5. Explain how hydrogen bonding accounts for many of water's unique properties.

Alignment of Unit Activities with Learning Goals

Table 3.5:

	Lesson 1	Lesson 2	Lesson 3
Presentation	*Introduction / Water Crisis*	*Science of Water*	*Nanofiltration*
Activity	*Student Reading, Data Worksheet*	*Water Lab Activity*	*Student Reading / Jarny / Filtration Lab*
Assessment	*Quiz/ Initial Ideas Worksheet*	*Label Results/ Quiz / Reflection Worksheet*	*Lab Results / Jarny, Reflection Worksheets*
Learning Goals ***Students will understand...***			

TABLE 3.5: (continued)

	Lesson 1	Lesson 2	Lesson 3
EU 1. A shortage of clean drinking water is one of the most pressing global issues	•		
EU 2. As a result of water's bent shape and polarity, water has unique properties, such as an ability to dissolve most substances. These properties are responsible for many important characteristics of nature.		•	
EU 3. Pollutants can be separated from water using a variety of filtration methods. The smaller the particle that is to be separated from a solution, the smaller the required pore size of the filter and the higher the cost of the process			•
EU 4. Innovations using nanotechnology to create a new generation of membranes for water filtration are designed to solve some critical problems in a cost-effective way that allows for widespread use.			•
Students will be able to...			
KKS1. Describe the global distribution of clean drinking water and explain some of the causes and consequences of water scarcity.	•		
KKS2. Describe different types of filtration in terms of the pore size of the filter, substances it can separate, and cost of use.			•

TABLE 3.5: (continued)

	Lesson 1	Lesson 2	Lesson 3
KKS4. Use laboratory procedures to compare the relative effectiveness of different filtration methods on particle separation.			•
KKS3. Describe the basic structure and charge distribution of water.		•	
KKS5. Explain how hydrogen bonding accounts for many of water's unique properties.		•	

Alignment of Unit Activities with Curriculum Topics

TABLE 3.6: Chemistry

Unit Topic	Chapter Topic	Subtopic	Fine Filters Lessons	**Specific Materials**
Structure of Matter	Electron Configuration	Atomic Structure	• Lesson 2 (L2): Science of Water	**Slides** • L2: 3-10
		Bonding	• Lesson 2 (L2): Science of Water	**Slides** • L2: 11-19

TABLE 3.6: (continued)

Unit Topic	Chapter Topic	Subtopic	Fine Filters Lessons	**Specific Materials**
Chemical Equilibrium	Solutions	Nature of solutions Precipitates Common Ion Effect	• Lesson 2 (L2): Science of Water • Lesson 3 (L3): Nanofiltration	**Slides** • L2: (all) • L3: (all) **Activity/Handout** • L2 – Science of Water Labs – Reflecting on Guiding Questions • L3 – The Filtration Spectrum – Which Method is Best? – Cleaning Jarny's Water – Comparing Filtration to Nanofiltration Lab Activities

TABLE 3.7: Biology

Unit Topic	Chapter Topic	Subtopic	Fine Filters Lessons	Specific Materials
Nature of Life	The Chemistry of Life	The Nature of Matter; Properties of Water; Carbon Compounds	**Fine Filters** • Lesson 2 (L2): Science of Water	**Slides** • L2: 20-32 **Activity/Handout** • L2 – Science of Water Labs – Science of Water Quiz

TABLE 3.8: Physics

Unit Topic	Chapter Topic	Subtopic	Fine Filters Lessons	**Specific Materials**
Light and Optics	Light Rays	Electron clouds Orbitals Charges	**Fine Filters** • Lesson 2 (L2): The Science of Water	**Slides** • L2: 5-16

TABLE 3.9: Environmental Science

Unit Topic	Chapter Topic	Subtopic	Fine Filters Lessons	Specific Materials
Water	Our Water Resources	Solutions to Water Shortages	• Lesson 1 (L1): The Water Crisis	**Slides** • L1: 1-27 **Activity/Handout** • The World-Wide Water Shortage: Student Reading • The Water Crisis: Student Data Worksheet • The Water Crisis Initial Ideas • Student Quiz

TABLE 3.9: (continued)

Unit Topic	Chapter Topic	Subtopic	Fine Filters Lessons	Specific Materials
	Freshwater Pollution	Wastewater Treatment Plants	• Lesson 2 (L2): The Science of Water • Lesson 3 (L3): Nanofiltration	**Slides** • L2: 1-34 **Activity/Handout** • L2: The Science of Water Quiz • L3: – Comparing Filtration and Nanofiltration Lab Activities – Reflecting on the Guiding Questions
		Pathogens	• Lesson 3 (L3): Nanofiltration	**Slides** • L3: 1-21 **Activity/Handout** • Reading: New Nano-Membranes • Which Method is Best? • Jarny Water Activity • Comparing Filtration and Nanofiltration Lab Activities • Reading: New Nano-Membranes

Fine Filters Pretest/Posttest: Teacher Answer Sheet

20 points total

1. Which of the following types of contaminants can nanomembranes filter out of water? For which of these, would you typically use a nanomembrane for removal? Explain why or why not. (1 point each, total of 12 points)

TABLE 3.10:

Can a nanomembrane filter it out?	Is a nanomembrane the best way to filter it out?
Bacteria **Yes** or No Yes or **No**	Why/why not: Bacteria are large enough that micromembranes can also filter them out of water. Micromembranes are less expensive to use and the large bacteria would quickly foul the nanomembrane.
Lead (Pb^{2+}) **Yes** or No **Yes** or No	Why/why not: Divalent ions (such as lead) are too small to be separated out by micro- or ultra-filtration. Nanofiltration can remove them from water and is less expense than reverse osmosis (which would also remove them).
Salt (Na^+ and Cl^-) Yes or **No** Yes or **No**	Why/why not: Monovalent ions are too small to be filtered out by current nanomembranes. Reverse osmosis must be used.
Sand **Yes** or No Yes or **No**	Why/why not: Sand is large enough that it can be filtered by a simple mesh cloth. This is less expensive to use and the sand would quickly foul the nanomembrane.

2. Name two benefits that nanomembranes bring to the filtration of water that help to address the world's problem of a scarcity of clean drinking water. (1 point each, 2 points total)

- More effective in removing particles of a given size
- More cost efficient than other technologies to remove small particles
- Nanofiltration can be engineered in many different ways (design flexibility)

Common Incorrect Answer:

- Can remove smaller particles than existing technologies (RO removes smaller particles)

3. Describe three ways in which nanofilters can operate differently than traditional filters to purify water: (2 points each, 6 points total)

- Layering: Nanomembranes can be uniquely designed in layers. This allows different parts of the membrane (the different layers) to be made out of different materials and have different properties to target different contaminants.
- Embedded Agents: Can embed specialized substances that do specific jobs in relation to certain kinds of contaminants – for example a chemical that kills bacteria on contact
- Water Channels: Create hydrophilic tubes in membranes that "pull" water through while keeping everything else out
- Electrostatic Repulsion 1: You can weave into the membrane a type of molecule than can conduct electricity and repel oppositely charged particles, but let water through.
- Electrostatic Repulsion 2: Pores of one to two nanometers in diameter create an electric field over the opening. This electric field is negative and repels negatively charged particles dissolved in water

- Self-Cleaning: Can send signal for them to self-clean (remove fouling residue)
- Less pressure is needed than conventional RO filters

The Water Crisis

Contents

- Introduction to the Water Crisis: Teacher Lesson Plan
- The Water Crisis: PowerPoint Slides with Teacher Notes
- The Water Crisis Student Data Worksheet: Teacher Instructions #38; Answer Key
- Fine Filters Initial Ideas: Teacher Instructions
- The Water Crisis: Quiz Answer Key

Introduction to the Water Crisis: Teacher Lesson Plan

Orientation

This lesson is an introduction to the context and human need for clean drinking water. Many students in the United States are unaware that in several parts of the world, clean drinking water is unavailable. This introductory lesson is intended to increase students' awareness of the problem in terms of human health and as a potential source of conflict between nations, especially as the world population grows.

A key goal is to spark students' interest by addressing a topic of personal and global significance. It is within the context of the urgent need for clean water by the people of several nations that they will better understand the significance that nanomembrane filtration technology could potentially have on helping to solve one of the current largest global problems. They will refine this understanding over the course of the unit and have a chance to reflect on their initial thoughts at the end of the unit.

- The Water Crisis PowerPoint slide set introduces facts about the global distribution of fresh water geologically. Areas of the world that do not have access to enough clean drinking water are highlighted. Per capita water usage, wealth, and access to sanitation are shown for several countries, and consequences from drinking contaminated water are highlighted. The final slide in the set introduces the driving questions for the unit.
- The Water Crisis: Student Data Worksheet captures the images of the data graphs and tables embedded in the slide set. The questions associated with the data sets that are designed to get students to think about the information portrayed. We recommend that the students do the data sheet as a homework assignment previous to seeing the slides. Alternately, they can complete it as you present the slides, pausing at each slide that portrays a data representation in order to give students time to think about the information depicted.
- The Initial Ideas: Student Worksheet gives students the chance to draw on their existing knowledge to formulate first thoughts about the unit. This is a great tool for eliciting students' prior knowledge (and possible misconceptions) related to the unit topics.
- The Water Crisis: Student Quiz can help you to assess the student understandings before the lesson is taught, so you can adjust the lesson appropriately, or it can be used as a summative evaluation after the lesson.

Essential Questions (EQ)

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

(*Numbers correspond to learning goals overview document*.)

2. How do we make water safe to drink?

3. How can nanotechnology help provide unique solutions to the water shortage?

4. Can we solve our global water shortage problems? Why or why not?

Enduring Understandings (EU)

Students will understand:

(*Numbers correspond to the learning goals overview document*.)

1. A shortage of clean drinking water is one of the most pressing global issues.

Key Knowledge and Skills (KKS)

Students will be able to:

(*Numbers correspond to the learning goals overview document*.)

1. Describe the global distribution of clean drinking water and explain some of the causes and consequences of water scarcity.

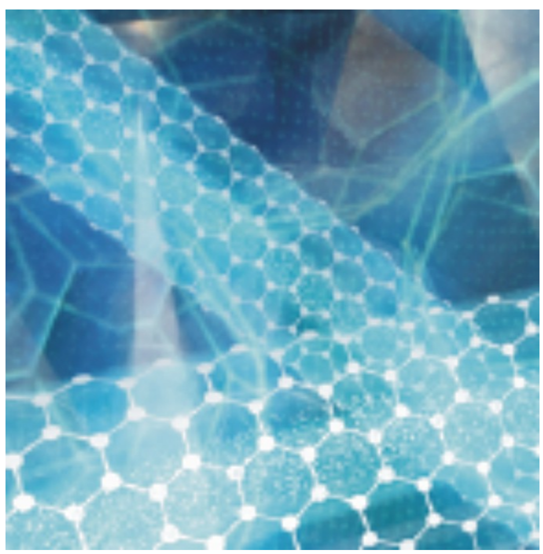
TABLE 3.11:

Day	Activity	Time	Materials
Prior to this lesson	*Homework*: Water Crisis: Student Data Worksheet	40 min	Photocopies of Water Crisis: Student Data Worksheet
Day 1 (50 min)	Hand out the Initial Ideas Student Worksheet and have students work alone or in pairs to brainstorm answers to the driving questions.	10 min	Copies of Fine Filters Initial Ideas: Student Worksheet
	Let students know that at this point they are just brainstorming ideas and they are not expected to be able to fully answer the questions.		Fine Filters Initial Ideas: Teacher Instructions
	Show the Water Crisis: PowerPoint Slides, using the question slides and teacher's notes to start the class discussion.	30 min	Water Crisis: PowerPoint Slides & Teacher Notes Computer and projector
	Hand out the Water Crisis: Student Data Worksheet if students did not complete it as a homework assignment the night before. Students can interpret the data representations or update their responses as you show the PowerPoint slide set.		Water Crisis: Student Data Worksheet

TABLE 3.11: (continued)

Day	Activity	Time	Materials
	Return to whole class discussion and have students share their ideas with the class to make a "master list" of initial ideas. The goal is not only to have students get their ideas out in the open, but also to have them practice evaluating how confident they are in their answers. This is also a good opportunity for you to identify any misconceptions that students may have to address throughout the unit.	10 min	
Day 2 (10 min)	Optional: Water Crisis: Student Quiz	7 – 10 min	Photocopies of Water Crisis: Student Quiz Water Crisis: Quiz Answer Key

The Water Crisis



A lack of clean water results in poverty, disease and death

Question

Have You Ever Gotten Sick from Drinking Impure Water? Do You Know Someone Who Has?

Clean Water is Necessary for Life

- Drinking
- Bathing
- Agriculture
- Sanitation

FIGURE 3.1

FIGURE 3.2

World Water Gap

- Despite the apparent abundance of clean water in the US and most of the developed world, more than 20% of the Earth's population lacks clean, safe drinking water.

FIGURE 3.3

How is the World's Water Distributed? I

- Less than 3% of Earth's water is fresh water
- The vast majority (97%) is undrinkable salt water in the oceans

How is Water Distributed? II

- Of the fresh water, most is in ice caps and glaciers, and some is in ground water
- Less than 1% is in more easily accessible surface water (lakes, swamps, rivers, etc.)

How is Water Distributed? III

- Most of the surface water is in lakes; a bit is in swamps and rivers
- The point: very little water is easily available for drinking

Water is Scarce in Some Regions

- 2.4 billion people live in highly water-stressed areas

No Single Cause for the Water Crisis

Many factors

- Climate and geography
- Lack of water systems and infrastructure
- Inadequate sanitation
  - 2.6 billion people (40% of the world's population) lack access to sanitation systems that separate sewage from drinking water
  - Inadequate sanitation and no access to clean water have been highly correlated with disease

Pollution is a Big Problem Too

- Types of pollution in fresh water:
  - Sewage is the most common
  - Pesticides and fertilizers

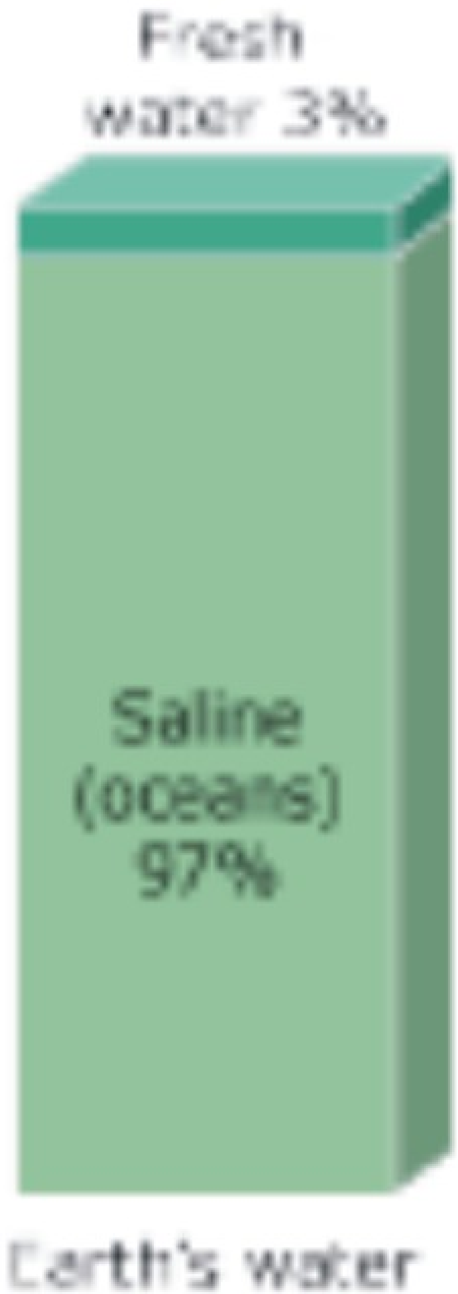


FIGURE 3.4

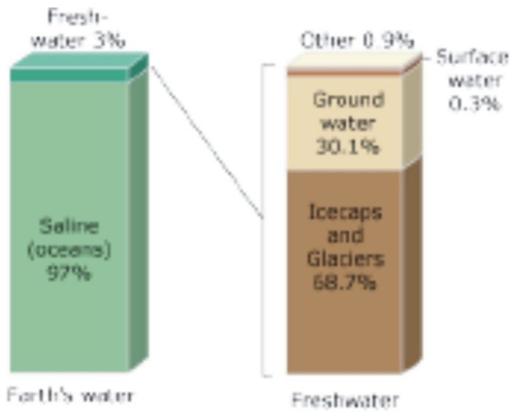


FIGURE 3.5

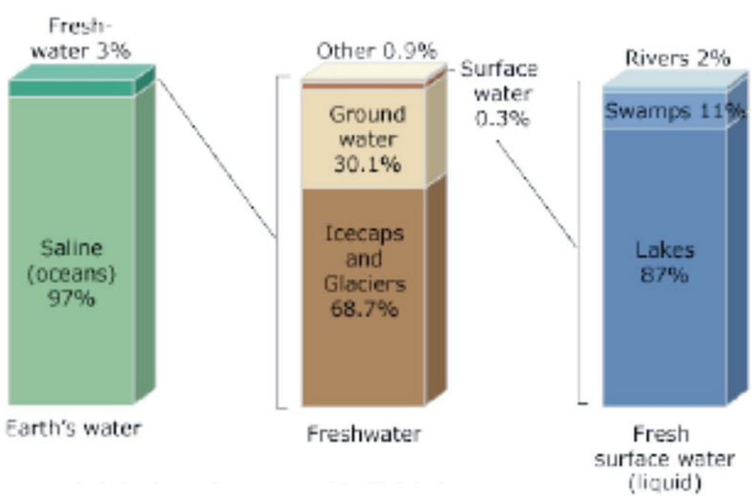


FIGURE 3.6

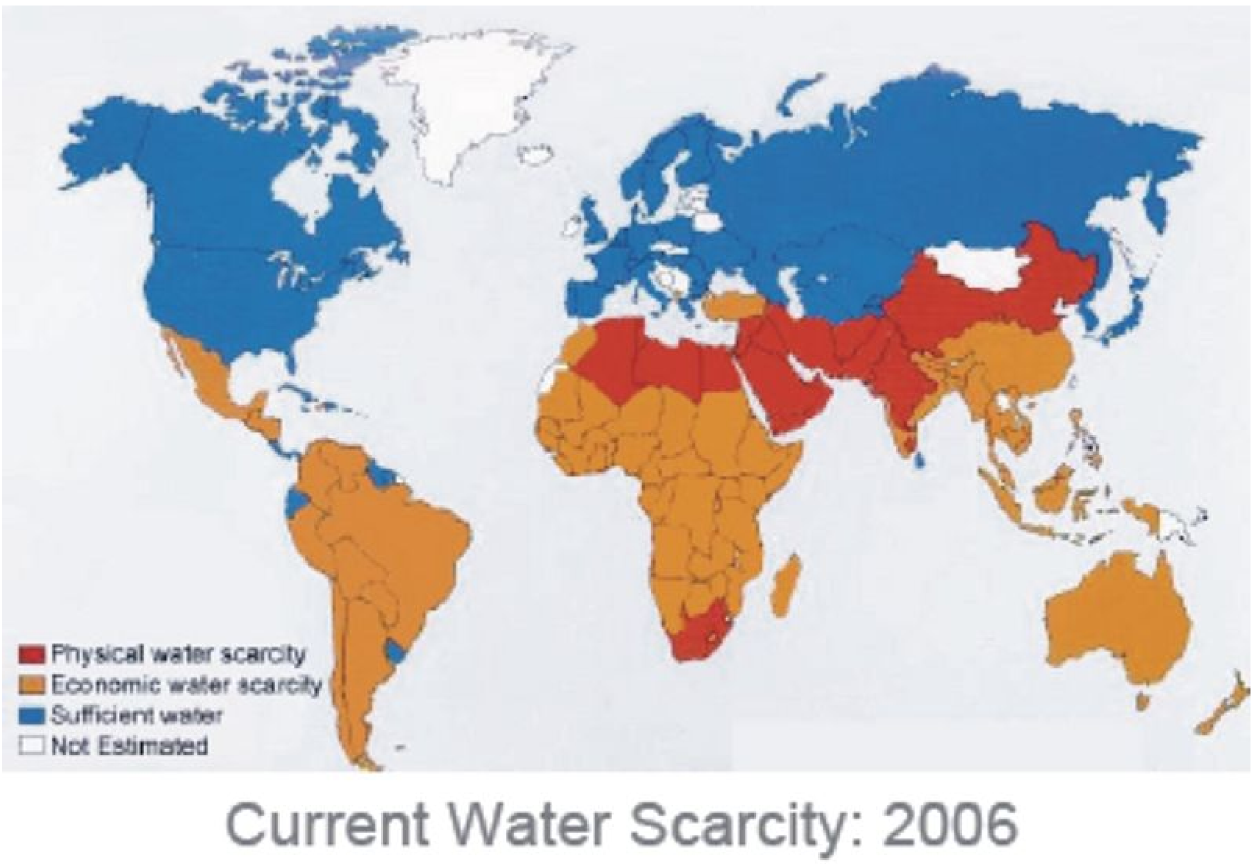

Physical water scarcity
Economic water scarcity
Sufficient water
Not Estimated
Current Water Scarcity: 2006

FIGURE 3.7

FIGURE 3.8

FIGURE 3.9

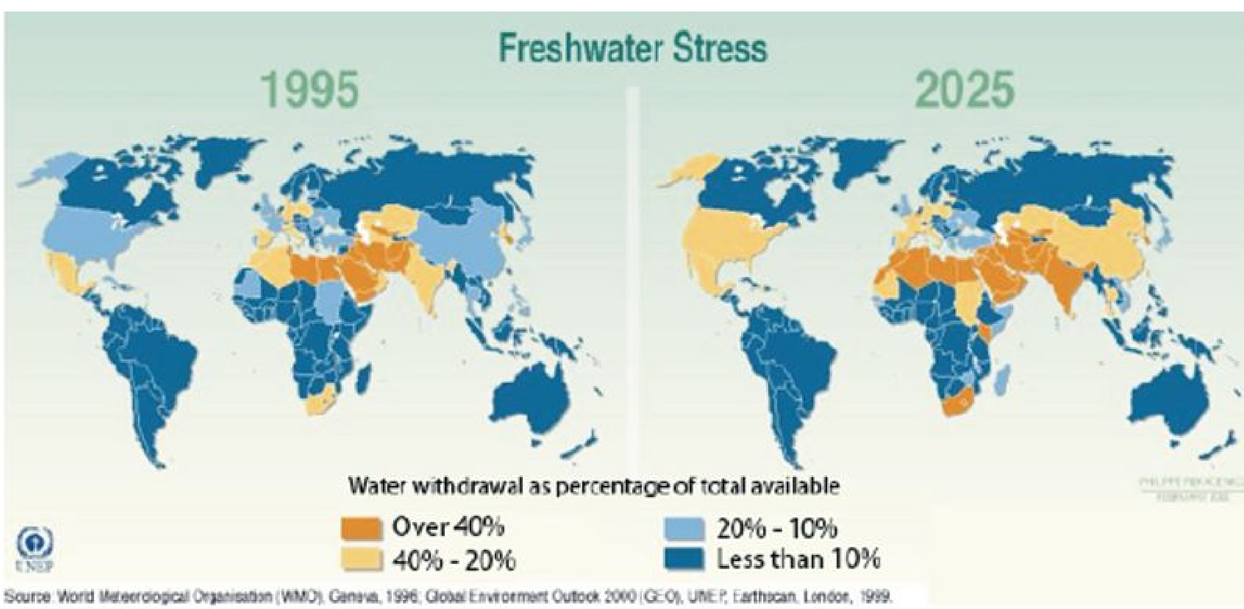


FIGURE 3.10

  - Industrial waste dumping
  - High levels of arsenic and fluoride

Water Scarcity is Projected to Worsen

Question

Why is the Water Shortage Projected to Worsen?

World Population is Increasing

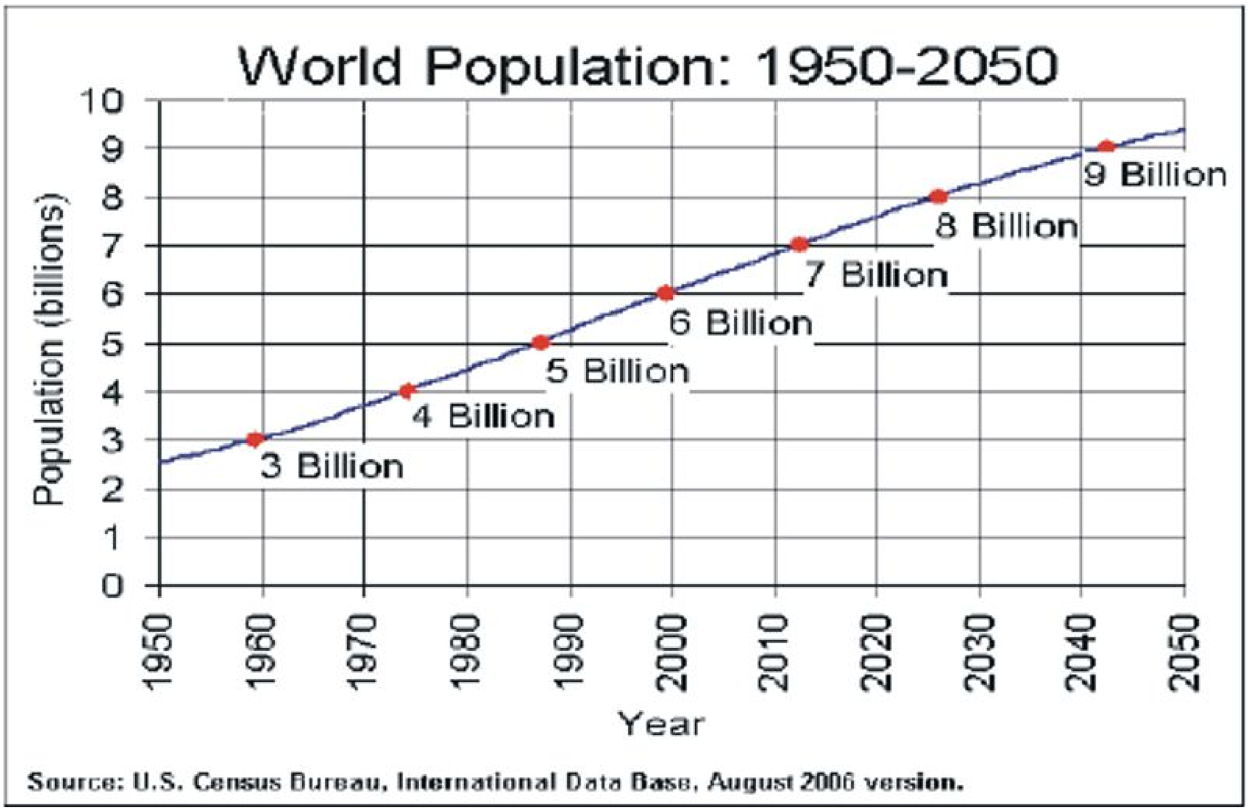


FIGURE 3.11

Question

In What Ways Would an Increasing World Population Affect Water Consumption?

Where Clean Water Use is Rising

Trends in Population and Water Use

Question

Is There a Relationship Between Poverty and a Lack of Clean Drinkable Water?

Countries Differ Widely in Water Usage

Countries Differ Widely in Wealth

Notice Any Correlations?

Many Without Access Live in Poverty

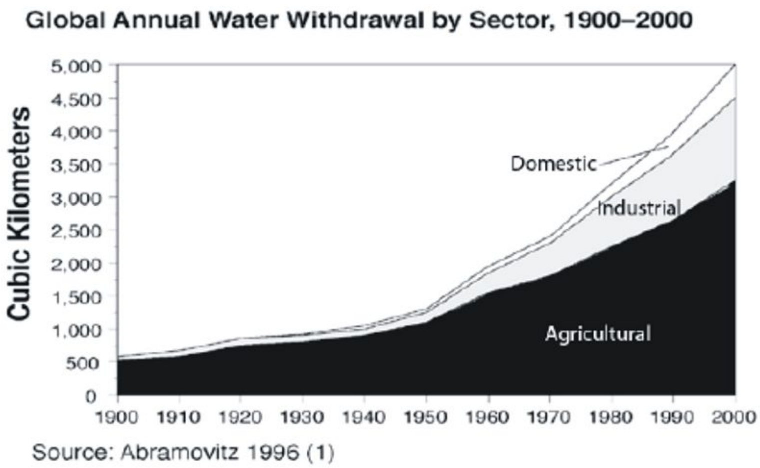


FIGURE 3.12

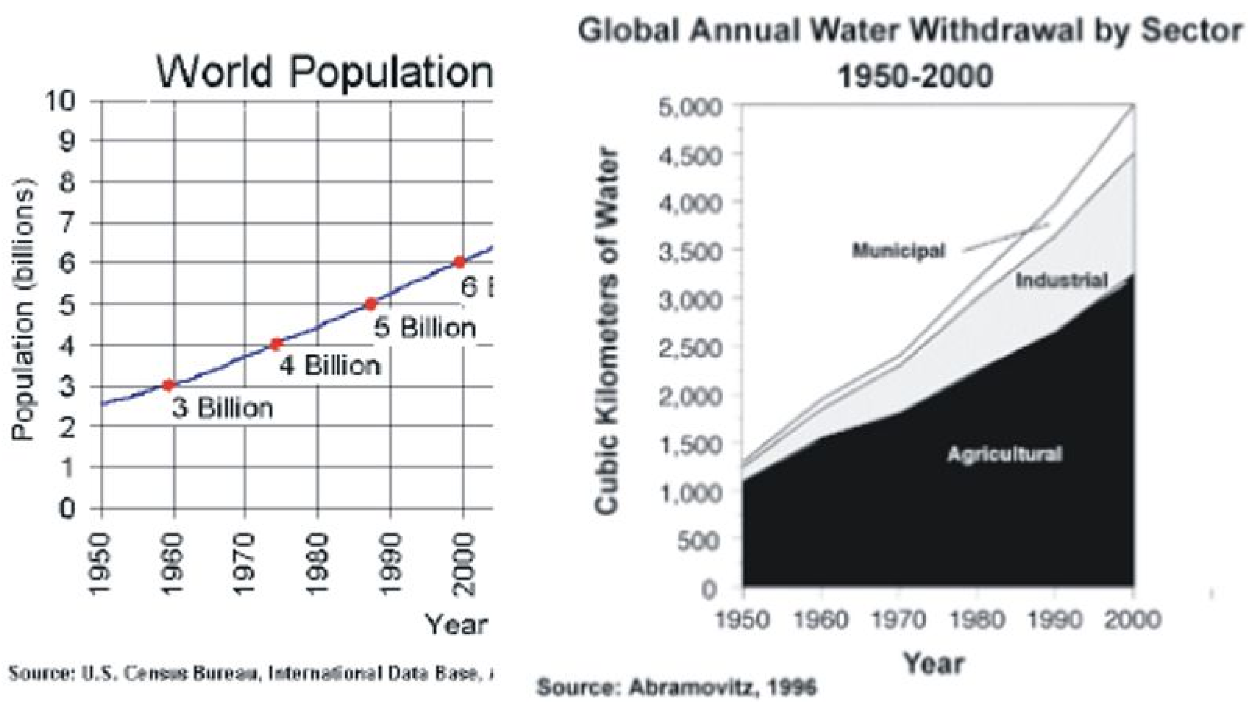


FIGURE 3.13

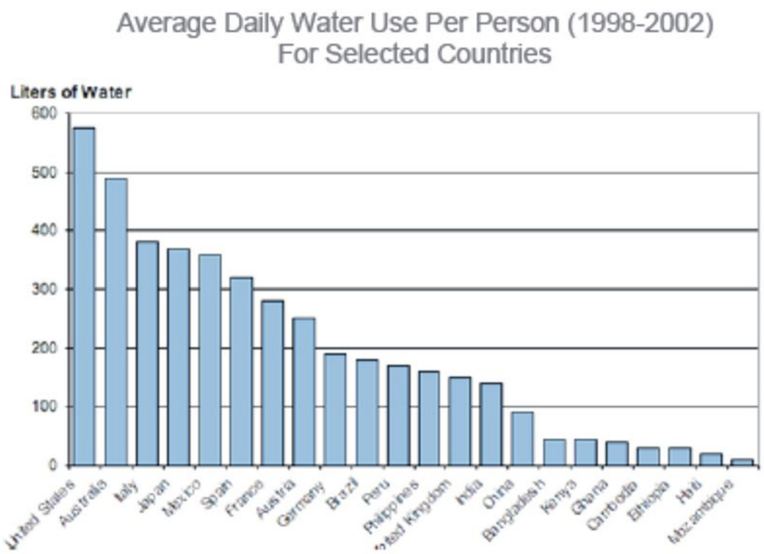


FIGURE 3.14

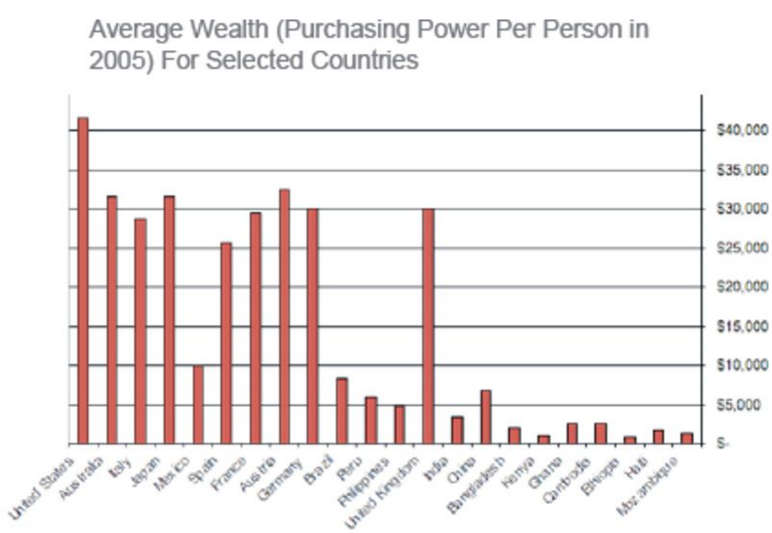


FIGURE 3.15

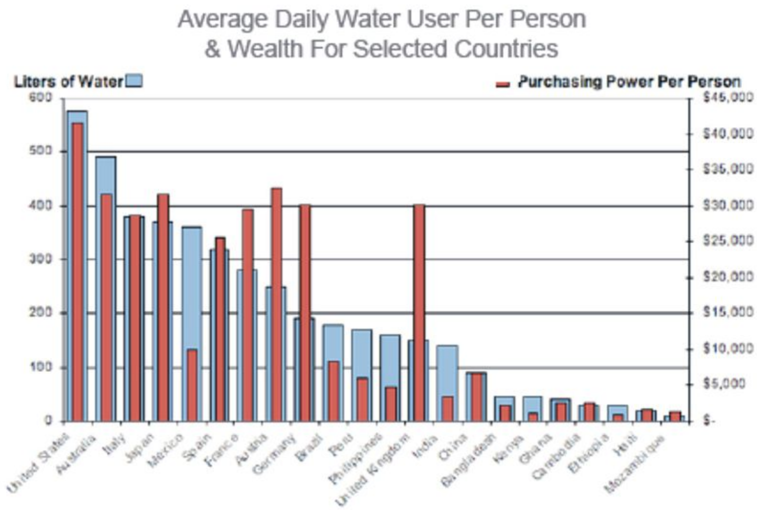


FIGURE 3.16

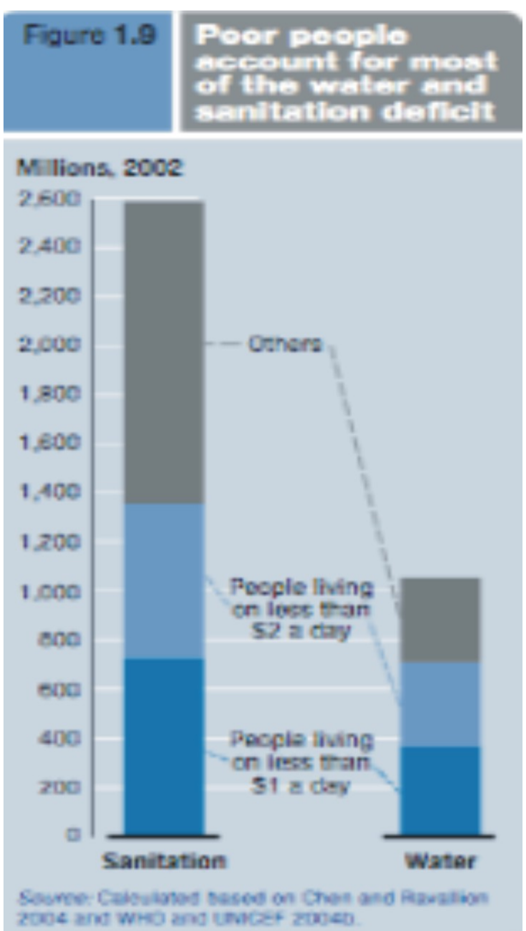


FIGURE 3.17

- People without clean water
  - Almost two in three people survive on less than $2 a day, with one in three living on less than $1 a day
- People without sanitation
  - Of the 2.6 billion people who do not have adequate sanitation, a little more than half live on less than $2 a day

Impact of Water Scarcity I

FIGURE 3.18
National Geographic &#8220 The World Water Gap&#8221 World Water Forum The Hague March 17-22 2000

- Health, education, and economic growth are impacted
- World Water Forum estimates:
  - 1.4 billion people lack clean drinking water
  - 2.3 billion people lack adequate sanitation
  - 7 million people die yearly from diseases linked to water
  - Half the world's rivers and lakes are badly polluted
  - Shortages could create millions of refugees seeking homes in a location accessible to water

Impact of Water Scarcity II

- World Health Organization estimates:
  - 80% of all sickness in the world is attributable to unsafe water and sanitation
  - The leading causes of death in children under 5 are related to unclean water; there are about 5,000 child deaths every day
  - Without action, as many as 135 million people could die from water-related diseases by 2020

Impact of Water Scarcity III

- Carrying water takes time!
  - Women and children can trek miles every day to retrieve water

FIGURE 3.19

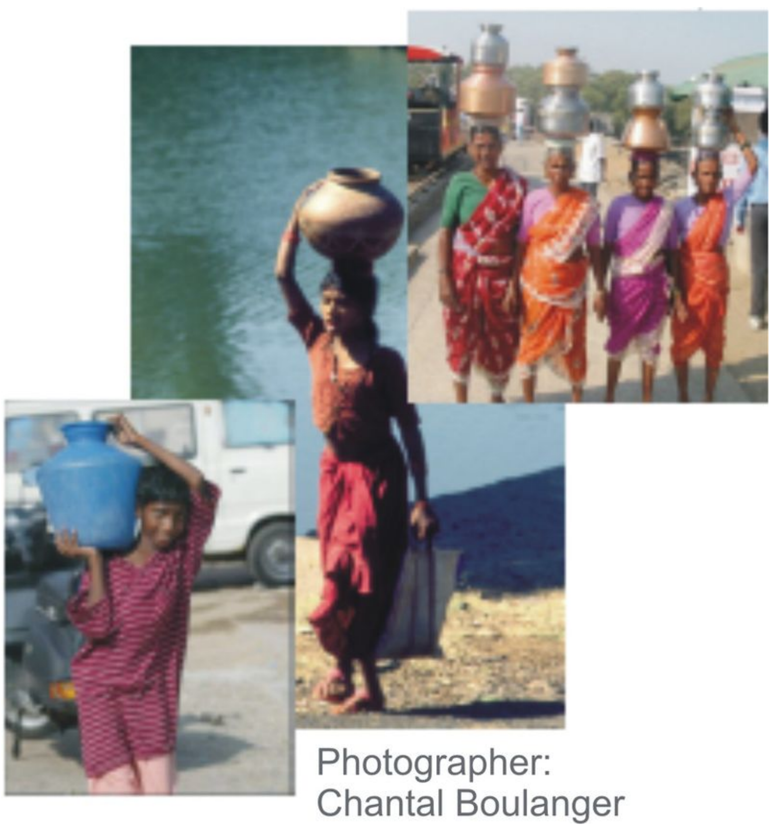


FIGURE 3.20

- This hard manual labor takes time that they might otherwise spend pursuing education or earning additional income

Children Carrying Water

FIGURE 3.21

War for Diminishing Resources?

"The next world war will be over water," says Vice President Ismail Serageldin from the World Bank

How Can We Address the Water Crisis?

- Use less water
  - More efficient irrigation, like drip irrigation
  - Low-flow shower and toilets
  - Use native plants for crops and landscaping
  - Eat less meat
- Find new sources of clean water
  - Um... Where? On the moon?
- Treat the undrinkable water that we have
  - Use reverse osmosis to desalinize salt (ocean) water
  - Clean polluted water using filters, chemicals, and UV light

Using Filters to Clean Water

- Pebbles, sand, #38; charcoal filter out large particles

FIGURE 3.22

- Membranes filter out smaller particles
- It is efficient to use a series of membranes to filter increasingly smaller particles

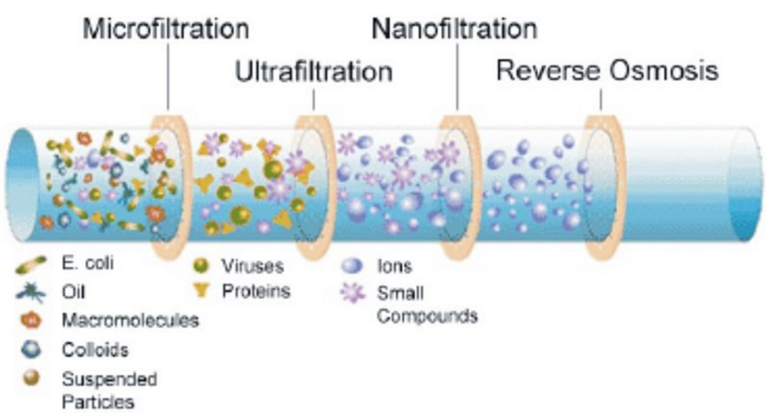


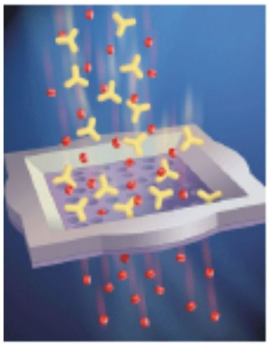
FIGURE 3.23

Can Nanotechnology Help?

- Nanotechnology offers new solutions to filter small particles
  - Unique properties at the nanoscale mean that membranes can be made to filter by electrical and chemical properties
  - A huge effort to create better, cheaper nanomembrane filters isv currently underway!

Questions

- How Do We Make Undrinkable Water Safe to Drink?
- How can Nanotechnology Help Provide Solutions to the Water Shortage?



Membranes clean water by filtering out unwanted substances

FIGURE 3.24

Professor Eric Hoek at UCLA is patenting a new nanomembrane filter

- Can We Solve Our Global Water Shortage Problems?
  - Why or Why Not?

Teacher Notes

Overview

This set of slides provides background information on the importance of clean water, why there is a problem with access to clean water, the geographical distribution of fresh water sources globally, a correlation between a country's wealth and water usage, and describes the impact of fresh water shortages on the human population. In this way we establish an important global context for learning about the potential of nanomembranes to help solve this problem of water shortage. These notes are intended to provide you with additional background content for each slide. Some slides will contain questions. These are invitations to engage students in an interactive classroom discussion about the question raised. You will also find a variety of resources for optional use to deepen your own knowledge or to engage students in an activity that relates to key points on the slide.

Slide 1: Title Slide

Slide 2: Have You Ever Gotten Sick from Drinking Impure Water? (Question Slide)

Discuss with your students what their experiences have been (or that they have known about) when someone drinks impure water. This discussion is intended to draw on students' personal understanding of the negative effects of not drinking pure water, so as to better peak their interest in the topic. In the event that students have not had experiences or heard about them, they may have heard about Montezuma's revenge!

Baytel Associates conducted a study to identify drinking water contaminants that cause health problems worldwide. They found so many different contaminants that they prioritized the list to include the twelve "if eliminated" that would have the greatest impact on public health. The twelve contaminants identified are: cholera, enteric bacteria, Rota- and polio viruses, intestinal protozoan, Ascaris (intestinal roundworm), Dracunculus medinensis (Guinea worm), Trichuris trichiura (whipworm), Enerobious vermicularis (pinworm), fluorides, heavy metals, nitrates, and synthetic chemicals.

From the report “Critical Drinking Water Contaminants: A Global Perspective,” as reported by *US Water News* online, June 1995. See http://www.uswaternews.com/archives/arcquality/5drink.html

Slide 3: Clean Water is Necessary for Life

Clean water is needed for these four major areas. Sanitation refers to the ability to provide adequate sewage disposal that separates sewage waste from drinking water supplies. Disease in a community is highly correlated with a lack of public sanitation.

Slide 4: World Water Gap

This slide informs students that many people globally do not have access to clean drinking water. The "gap" is a term to describe the difference between the number of people who need clean drinking water compared with the number of people who need clean drinking water. Later we’ll see a global map of fresh water distribution.

Based on data from NASA, the World Health Organization, and other agencies, a report produced by the United Nations Environment Programme predicts:

- Severe water shortages already affect at least 400 million people today and are projected to affect 4 billion people by 2050. Southwestern states such as Arizona will face severe fresh water shortages by 2025.
- Adequate sanitation facilities (bathrooms) are lacking for 2.4 billion people, about 40% of humankind.

See http://www.usatoday.com/news/nation/2003-01-26-water-usat_x.htm

Slide 5: How is the World’s Water Distributed? I

Slides 5, 6, and 7 show the distribution of water globally. Many students do not know that most of the world’s water is salt water (undrinkable and/or unusable for agriculture). The green box shows a physical depiction of the amount of fresh water relative to salt water, globally.

Why can’t we use salt water to drink or for agriculture?

Some students do not understand why we cannot drink salt water. Department of Energy’s scientist, Prof Bill’s, explanation of why we cannot drink salt water is brief and to the point: “Humans can’t drink salt water because the kidneys can only make urine that is less salty than salt water. Therefore, to get rid of all the excess salt taken in by drinking salt water, you have to urinate more water than you drank, so you die of dehydration.”

Why can’t salt water be used for agriculture? In general, too much salt will interfere with the chemistry in a plant that allows the plant to make food and to obtain energy from food. In addition, plants usually get their water through their root system by a process called osmosis (students who have had biology will know about this process). Osmosis involves the passage of water across the membrane of a cell from an area of greater concentration to an area of lesser concentration. If the plant is surrounded by salt water, the plant will tend to pass fresh water from their inside structures to the soil through the roots, causing the plant to lose, not absorb water.

There is a type of plant, called halophytes, that have special structures that separate the salt in such a way that it is prevented from mingling with the rest of the plant, allowing the plant to survive in a salt water environment.

Slide 6: How is Water Distributed? II

This slide depicts the section in the green box representing the proportion of fresh global water, expanded to show where the 3% of fresh water may be found: 68.7% icecaps and glaciers, 30.1% ground water, and only 0.3% surface water.

Slide 7: How is Water Distributed? III

This slide depicts the distribution of the 0.3% surface water: 87% lakes, 11% swamps, and 2% rivers.

Slide 8: Water is Scarce in Some Regions

This calculated approximation, that 2.4 billion people are living in highly water-stressed areas, comes from N.Utsumi, *Thesis,* The University of Tokyo (2006).

Fresh water scarcity or stress is described in a variety of ways.

This is a map from a global view showing the geographic distribution of fresh water, either as surface water or in underground aquifers, as it relates to the population's need for fresh water in that region. Depending on the area's population density and the climate's ability to renew these water supplies, a geographic area can be described by the percent of its available fresh water being used annually compared to how much fresh water is potentially available for use. The higher the percent of water being used compared to what is potentially available, the more **scarce** the fresh water supply. The total potentially available fresh water cannot be completely used. Water availability depends on the climate, the season, the amount of snowmelt, and the infrastructure to capture, store, clean, and deliver it.

Water scarcity is often described in two ways:

Physical water scarcity is a term used to describe an area whose primary water supply is developed at 60% or greater than the total potential capacity. One must understand that the total potential capacity includes water that can never be entirely accessed. These countries do not have sufficient fresh water to meet their demands for agriculture, domestic water, industrial sectors, and environmental requirements. Food has to be imported or salt water must be treated by an expensive desalination process in order to get enough fresh water for agriculture. Agriculture consumes about 70% of fresh water supplies.

Economic water scarcity is a term describing a region that has adequate physical water resources to meet their water supply needs, but must increase the availability of the water through additional storage and conveyance facilities. Most of these countries face severe financial and development capacity problems for increasing the primary water supply, by building the needed infrastructure.

Water shortages are greatest in equatorial regions with increasing populations.

Slide 11 will show freshwater stress simply as the water withdrawal as a percentage of the total available. These are associated with different percentages.

From *Science,* August 25, 2006, published by AAAS:

Water scarcity can be an index defined as $\mathrm{Rws} = (\mathrm{W} - \mathrm{S})/\mathrm{Q}$ where W, S, and Q are the annual water withdrawal by all the sectors, the water use from desalinated water, and the annual renewable fresh water resources (RFWR), respectively.

Slide 9: No Single Cause for the Water Crisis

This slide highlights the major causes for the water crisis. An arid climate does not produce much rainfall. Areas with sufficient rainfall and fresh water supply often lack systems to clean and deliver water to the people, especially in rural areas. It is estimated by the World Health Organization that 40% of the world's population lack sufficient sanitation systems to keep the potable (drinking) water separate from human wastes.

Arsenic and fluoride are pollutants that leach out of rocks into the water in some areas. While small quantities of fluoride are good for teeth, larger quantities are bad. These must be removed before the water is considered to be safe for drinking.

Slide 10: Pollution is a Big Problem Too

The most common type of pollution is untreated sewage that mixes with the drinkable water supply. Sewage contains disease-causing bacteria. Secondly, agriculture contributes pesticides and fertilizer. The pesticides contain poisonous substances that dissolve in water and the fertilizer breaks down to release nitrates into the water. Industrial pollutants contribute heavy metals to the water supply in some areas. All of these must be removed from water, according to clean water standards, for water to be safe to drink.

Slide 11: Water Scarcity is Projected to Worsen

This slide depicts the global distribution of fresh water in the year 1995 and the predicted water distribution in the year 2025. The colors represent the percentage of water withdrawn compared with the total amount of water available. The light orange represents mild water stress and the darker orange represents extreme water stress. The blue areas are considered to be free from freshwater stress.

The graph in the lower right corner shows the amount of people, in billions, suffering from water stress and scarcity, in 1995, then as projected to the year 2050.

It is important to keep in mind that the total possible amount of fresh water can never be fully used. There is high variability of water resources in space and time. River flow depends upon the seasonal climate. An example would be that what is available as snowmelt into the rivers will not be available in the dry season.

Slide 12: Why is the Water Shortage Projected to Worsen? (Question Slide)

Discussion Question for Students: Ask your students why they think that water shortages are predicted to become worse over time.

Although there are current supply problems that need to be solved, as shown by slides 9 and 10, the increase in demand for water is an even bigger factor.

This predicted increase in demand for water is based largely on projected population growth. The larger the population, the more agriculture is required to feed people. Agriculture currently accounts for about 70% of the fresh water usage. The other factor that enters into this prediction is the increasing economics of currently underdeveloped countries.

Slide 13: World Population is Increasing

This graph presents the latest estimates and projections of world population from the U.S. Census Bureau. The world population increased from 3 billion in 1959 to 6 billion in 1999, a doubling that occurred over 40 years. The Census Bureau's latest projections imply that population growth will continue into the 21st century, although more slowly. The world population is projected to grow from 6 billion in 1999 to 9 billion by 2042, an increase of 50% that is in approximately 43 years.

Slide 14: In What Ways Would an Increasing World Population Affect Water Consumption? (Question Slide)

This is a good time for students to brainstorm what water is used for and relatively how much water is used. The next slide depicts an increase in population.

Slide 15: Where Clean Water Use is Rising

This slide depicts the number of cubic kilometers of water withdrawn for municipal, industrial, and agricultural purposes over a period of 100 years, from 1900 to 2000.

The most important point is that agriculture requires at least two-thirds of all of the water withdrawn. As the graph indicates, all uses of water rise as population increases.

Slide 16: Trends in Population and Water Use

This figure shows the two graphs, previously seen, side-by-side, in order to facilitate easier comparisons. Students can easily notice that the trends in the increase of population over time parallel the increase in water consumption.

Slide 17: Is There a Relationship Between Poverty and a Lack of Clean Drinkable Water? (Question Slide)

Answer: There are strong correlations between a country's financial wealth and the presence of clean, drinkable water. To clean and deliver drinkable water requires expensive infrastructures of cleaning systems and pipes to transport the water in areas where water is present in sufficient quantities to meet the populations' needs. In areas where there is not enough natural fresh water sources to meet the needs (drinking water, sanitation, industry, and agriculture) an expensive system must be employed to remove the salt, (desalination), from the water. The World's Water Report says that 1 in 6 people on earth suffer from extreme poverty.[1]

The distribution of access to adequate water and sanitation in many countries mirrors the distribution of wealth. Access to piped water into the household averages about 85% for the wealthiest 20% of the population, compared with 25% for the poorest 20% .

As an optional activity, you may want students to examine a set of tables with information on different countries' water in cubic meters per person and each country's gross national product. Students could work in groups to produce a line graph for these two variables. They could share their interpretation of the graphs. As a less time-consuming alternative activity, students could simply scan the tables with partners to notice the patterns shown by these two variables.

An important understanding to be developed by students during this study of nanofiltration is that the current world water crisis reflects the economic and political decisions made by countries and people.

Information to design an activity like this is available at: https://cia.gov/library/publications/the-world-factbook/index.html.

[1]*Water : A Shared Responsibility.* UN Report, produced by Berghahn Books and United Nations Education, Scientific and Cultural Organization (UNESCO).

Select a country from the menu at the top.

Slide 18: Countries Differ Widely in their Water Usage

The next three slides are shown to give students an opportunity to make the connection between a country's water usage and per capita wealth. Though for the higher amounts of water usage, there is not an exact correlation with wealth; the low wealth countries consistently show low per person water usage.

This slide depicts a variety of countries' average daily water usage per person between the years of 1998 and 2002. Some of the countries with especially high water usage and some of the countries with low water usage are displayed. For a list of all of the countries' average daily water usage during this same time frame, refer to http://www.cia.com.

Slide 19: Countries Differ Widely in Wealth

This slide shows the same countries' wealth depicted in terms of purchasing power per person for each country in 2005. These figures are from http://www.cia.com.

Slide 20: Notice Any Correlations?

This slide displays the countries' average daily water use per person graph, seen on slide 18, superimposed on the wealth graph (depicted as purchasing power per person).

This is a good opportunity for students to look at the data displayed and make statements about the relationships from the two variables displayed. If students disagree, it is an opportunity for them to choose evidence to support their argument. You might ask them what other information they would need to draw a conclusion.

Question for Students: Is there any evidence that a country's per person water usage has anything to do with a country's per person purchasing power?

Slide 21: Many Without Access Live in Poverty

This graph shows the approximate total number of people, in millions, who don't have access to sanitation (bar on the left) and to clean water (bar on the right). More than two-thirds of the people who don't have access to clean water make less than $2 a day. A little over half of the people who don't have access to sanitation make less than $2 a day.

Slide 22: Impact of Water Scarcity I

This slide highlights the impact of water scarcity on the human condition, globally. This is a good teachable moment. This slide says that 2.3 billion people lack adequate sanitation; slide 9 mentions the estimate of 2.6 billion people.

Question for Students: How hard is it to estimate this phenomenon?

Sanitation and a lack of clean drinking water are related because human feces and urine contain and grow bacteria that cause disease in humans. If there is no way of separating this sewage from a fresh water source, people will become diseased when drinking this water.

Slide 23: Impact of Water Scarcity II

This slide presents additional information from the World Health Organization regarding the impact of water scarcity.

It also includes a prediction for 2020 if population continues to rise, and fresh water availability continues to be scarce.

The leading cause of death for children in general is associated with respiratory illnesses. The second leading cause of death is diarrhea, which is related to unclean water.

Slide 24: Impact of Water Scarcity III

This slide shows young women and children carrying water to their homes. The impact on a child's or a woman's time in water scarce areas is greater than that on an adult's or a man's, as it is a cultural tradition in many regions to assign the task to children (or more often to very young women) of bringing water from its source to the home. This can require up to 6 miles of walking a day.

Question for Students: How would carrying water a few hours each day for your family impact your life? What would you have to give up?

Slide 25: Children Carrying Water

This is a slide that shows just a few of the amazing pictures publicly available of children carrying water.

Slide 26: War for Diminishing Resources?

This slide highlights a controversial prediction among many authorities. Water is not always a renewable resource. Most of the water used is found stored naturally underground in aqueducts that have been the result of rainwater accumulated over decades, if not centuries. In some regions, like Los Angeles, California, the water is being drained from these aqueducts at a faster rate than natural rainwater can replace. Further, draining the aqueducts at a fast rate can cause subsidence, the collapsing of the land, allowing the ocean to infiltrate and contaminate fresh underground water areas.

Slide 27: How Can We Address the Water Crisis?

Agriculture consumes about 70% of fresh water supplies, so efficiencies there—like more efficient irrigation methods—could have the most impact. But there are a lot of things that we can do on the smaller scale, too, like conserving water at home and in our gardens. Lots of web sites offer water saving tips. A good example is http://www.wateruseitwisely.com

Even eating less meat saves a lot of water. Livestock consume huge resources. Author of *The Food Revolution,* John Robbins, estimates that "you'd save more water by not eating a pound of California beef than you would by not showering for an entire year."

Can we find new sources of water? Not really, but we could treat the undrinkable water that we have. But treatment takes energy and requires technology, so it costs money.

We can't drink salt water or use it for agriculture, but we could treat it to take out the salt using reverse osmosis techniques. This is a particularly expensive process, because it requires a lot of pressure (which means a lot of energy).

Ground water and waste water this is contaminated can also be cleaned. For example, bacteria can be killed by exposing the bacteria-laden water to UV light and chlorine. We can also clean water by filtering it.

Slide 28: Use Filters to Clean Water

Water can be cleaned by pouring it through pebbles, sand, and charcoal. Membranes can also be used to filter out small particles. A membrane is a structure that lets some things through and others not. You may want to check that your students know what a membrane is.

An efficient method of cleaning water is to use a series of increasingly smaller filters that filter out increasingly smaller particles. This picture highlights the membranes that clean water and the particles that each type of membrane removes. In general, the smaller the membrane, the more pressure is needed to push the water through the membrane, and the more expensive is the process. Usually larger membranes are used as prefilters to filter out the larger particles that would easily clog or "foul" the smaller membranes.

Slide 29: Can Nanotechnology Help?

Nanotechnology is a new area of engineering in which many laboratories are working to create innovatively designed membranes that have a hope of filtering water more cheaply and more flexibly that those currently on the market.

Slide 30: Questions

The questions on this slide guide this unit. Though the unit is built around solving the polluted water problem for the town of Jarny, students should also learn something about water purification processes and the basic science of water. This understanding will help them to reflect knowledgably on the global health problem of a lack of clean drinking water.

Resources

The World Water Forum is a group that has met for the fourth time to consider issues related to global water scarcity and fresh water sustainability. The fourth one was attended by governmental delegations from 148 countries, 200 legislators, 160 representatives of local authorities, 185 children, and a plethora of non-governmental organizations, UN agencies, experts, academia, water managers, and media representatives who met in Mexico City from March 16 through March 22 to share their local experiences, in order to make a difference in a world in which billions of people still lack access to safe water and sanitation. This group has published a report that highlights the conclusions and agreements made during this conference. The final report can be found at http://www.worldwaterforum4.org.mx/files/report/Final

Water Crisis: Student Data Worksheet Teacher Instructions #38; Answer Key

This activity allows student to become actively involved in interpreting the different figures and graphs that are used in the Water Crisis PowerPoint presentation. Providing them with an opportunity to think about what each representation means before presenting the slides will allow for greater engagement on the part of your students and develop their graph interpretation skills. You may want to assign this worksheet as a homework assignment before you show the slides, or have students fill out the worksheet as you come to each of the slides, but before discussing them.

Note: Figure 2 is more easily distinguished in color, so you may want to pass out color copies of the student worksheet to your students. Otherwise, students may need to see the slide presentation to answer the questions associated with Figure 2.

Directions

Using the graphs and maps, answer the following questions. This activity will give you the opportunity to interpret some of the graphs and maps that you'll see during the Water Crisis slide presentation during class.

1. According to the bar graphs in Figure 1, **what percentage** of the world's water is **fresh water**?

3%

2. What do these three divided bar graphs tell you about **where** the Earth's fresh water resides?

The earth's fresh water resides in icecaps and glaciers, ground water, lakes and swamps and rivers.

Physical water scarcity refers to the lack of water to meet domestic, industrial, and agricultural needs. Areas of physical water scarcity are shown in red on the map in Figure 2 below. Economic water scarcity means that an area or country has insufficient financial resources to deliver safe, clean water to those areas that need it for drinking or agriculture. Areas of economic water scarcity are shown in orange in Figure 2.

Answer questions 3-8 based on information from the map in Figure 2.

2. Name the countries or global areas that are experiencing **physical water scarcity.**

In Northern Africa: Algeria, Libya, and Egypt. In the Middle East: Saudi Arabia, Iraq, Turkey, Iran, Pakistan, Afghanistan, much of India, Northern China and some smaller countries.

3. What would you predict the climate to be in these areas and why?

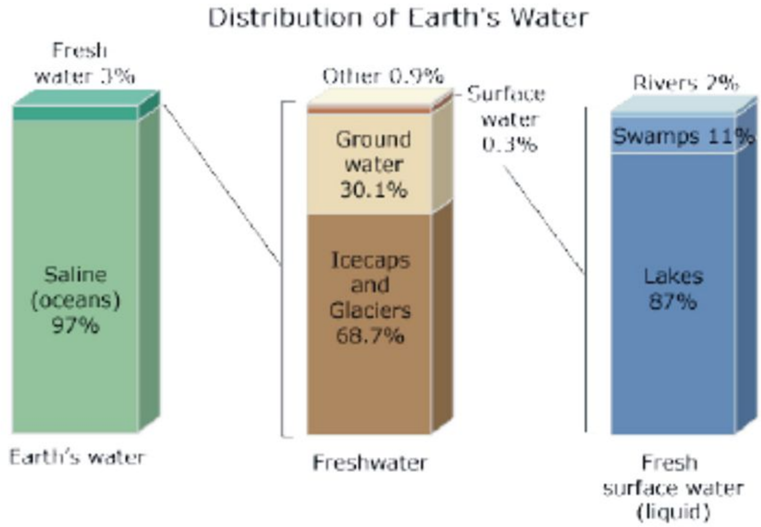


FIGURE 3.25
Distribution of earth&#8217 s water.

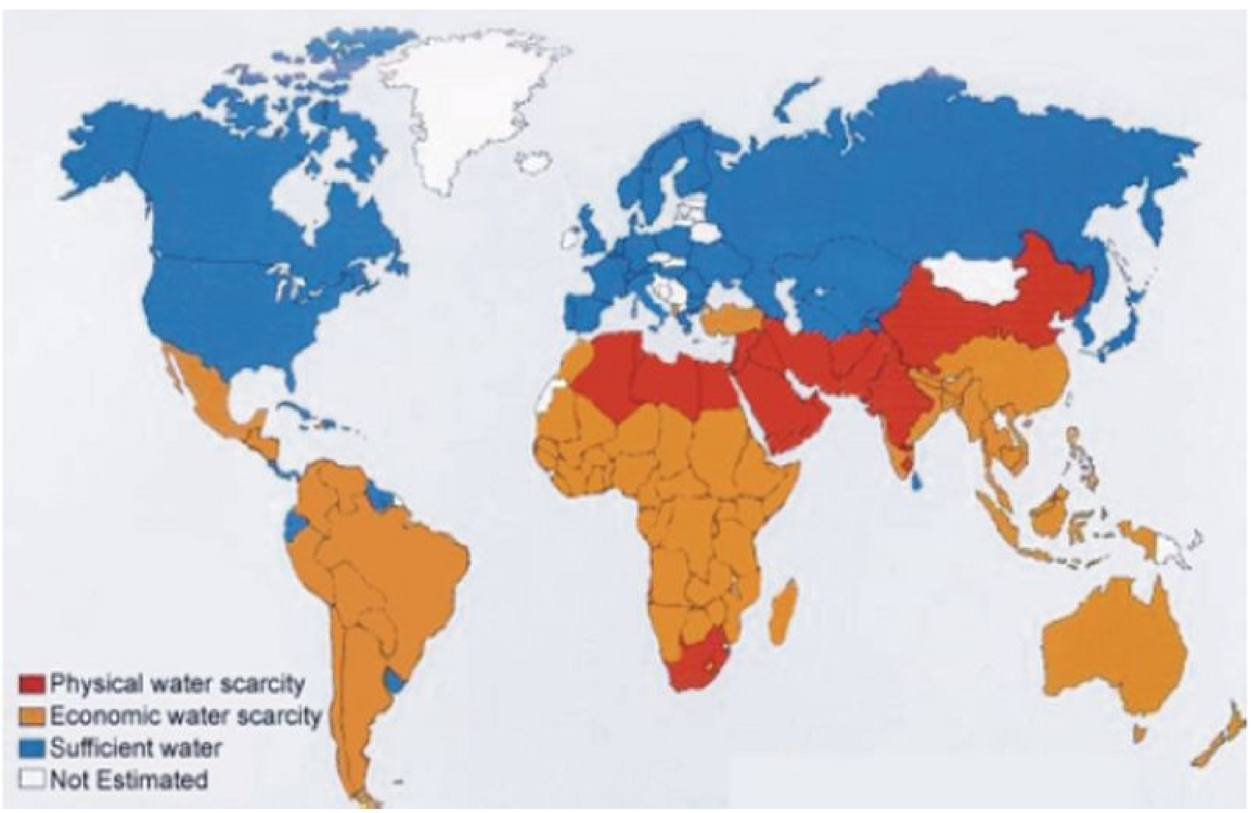


FIGURE 3.26
Global map of water scarcity in 2006.

These areas would most likely have hot and dry climates, because the map indicates they have a physical water scarcity.

4. Name the countries or global areas that are experiencing **economic water scarcity.**

Central and most of South American, central and much of southern Africa, China, Viet Nam, Laos, Cambodia, the Philippines and the rest of the East Indies, and Australia.

5. Name the countries or global areas that are **not** experiencing any water scarcity.

North American countries and Northern Eurasia.

6. What do you predict the difference in per capita income (average income per person) would be between regions with plenty of water and regions with economic water scarcity?

Because water is needed for personal, industrial and agricultural use, it makes sense that those countries with greatest access to water are among the wealthiest nations as well.

7. The southwestern United States is typically characterized as having a dry, arid climate. Why might this region be shown as having plenty of water even if it is dry and arid?

Students may guess, correctly, that we divert water from northern rivers to the southern drier lands. They may also guess that there are rich sources of underground aquifers that supply water.

When water is taken from a natural source for human use, it is called "water withdrawal." However, a country can never withdraw all of the fresh water that is theoretically available within its borders. Much of it is seasonal, or part of flood runoff, or rain that cannot possibly all be captured. Countries that withdraw a high percentage of their available fresh water are said to be under "freshwater stress" and are in danger of becoming considered "water scarce." In the map in Figure 3, the light orange represents mild freshwater stress and the darker orange represents extreme fresh water stress. Blue areas are considered to be free from freshwater stress.

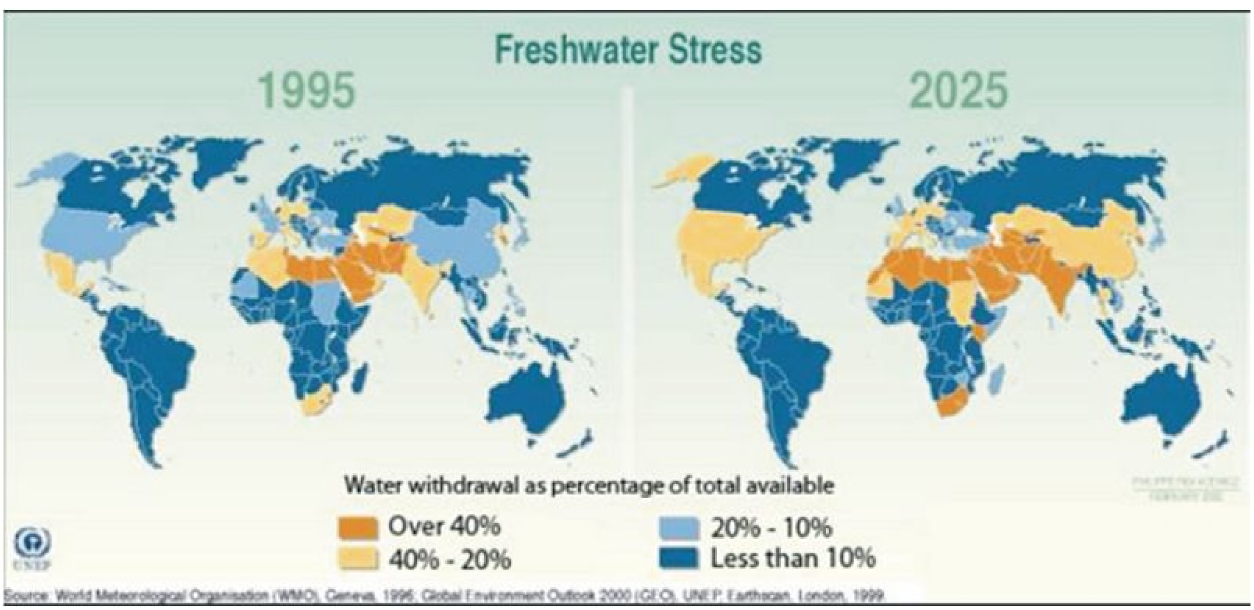


FIGURE 3.27

Global map of freshwater stress 1995 and 2025 *predicted*.

8. Compare the two maps above, showing freshwater stress from the year 1995 and projected to the year 2025. What are the changes that you see happening in which areas?

America and Alaska go from a water withdrawal of $10-20\%$ to $20-40\%$, as does Mauritania and the Sudan in Central Africa. China also increases its' water use. Experiencing over 40% of water withdrawal now is Uganda, South Africa, and India.

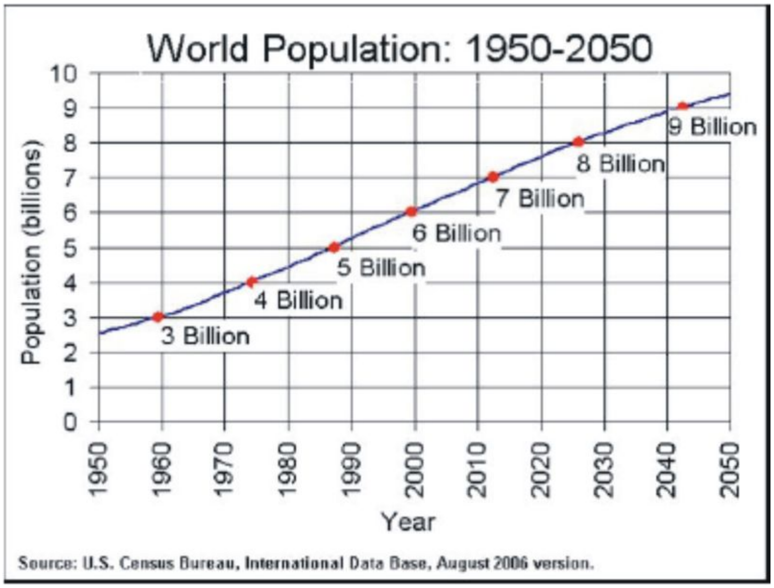


FIGURE 3.28
World population from 1950 to 2050 *predicted*.

9. In Figure 4, what trend do you see in for the global population?

The population increases by three times from 1950 - 2050.

10. What would you predict the global population to be in 2060? Justify your prediction.

The population would likely increase to 10 billion people, based on the trend depicted for the previous two decades.

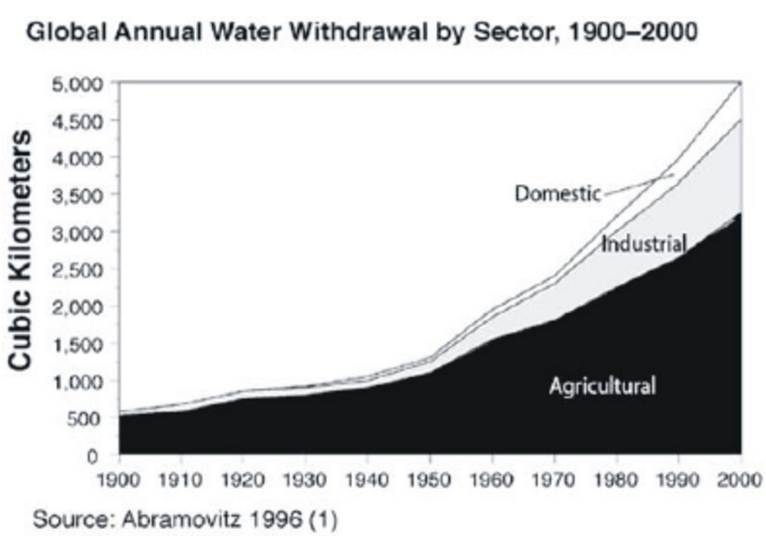


FIGURE 3.29
Global annual water withdrawal by sector 1900-2000.

11. According to the graph in Figure 5, which sector uses the most water?

Agriculture

12. Which sector uses the least amount of water?

Domestic

13. How does the trend in water consumption (Figure 5) compare to the trend in population (Figure 4) for the time period 1950-2000?

The trends parallel each other.

Average Daily Water Use Per Person (1998-2002) For Selected Countries

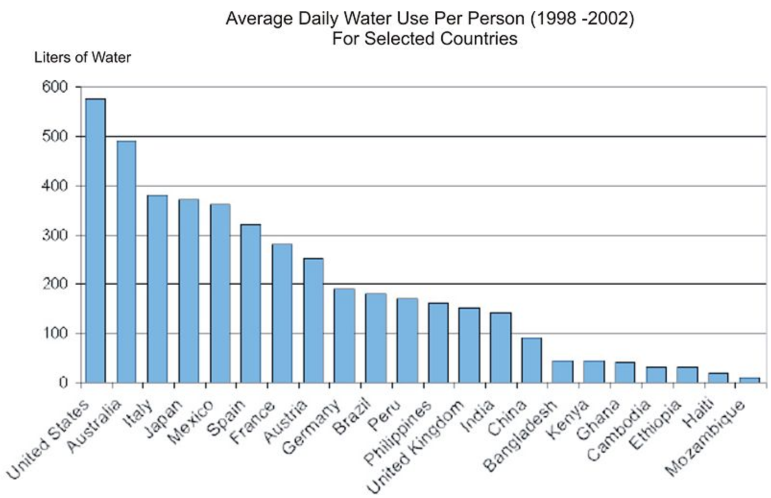


FIGURE 3.30
Average daily water use per person for selected countries from 1998 to 2002.

14. According to Figure 6, which countries consume the most water?

United States, Australia, Italy, Japan, Mexico, Spain, France and Austria.

15. Which countries consume the least water?

China, Bangladesh, Kenya, Ghana, Cambodia, Ethiopia, Haiti, and Mozambique.

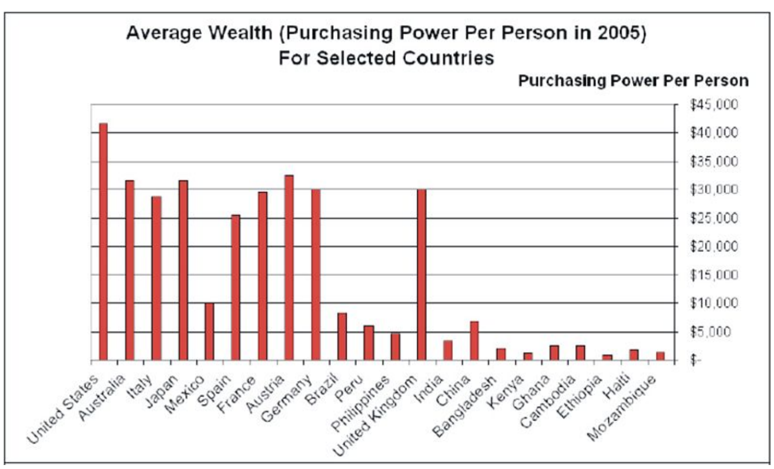


FIGURE 3.31
Average wealth for selected countries *purchasing power by person in* 2005.

Answer questions 16-19 based on information from the graph in Figure 7.

16. How many countries have an average per person purchasing power of less than $\$10,000$?

13

17. How many countries have an average per person purchasing power of more than $\$25,000$?

9

18. How many countries have an average per person purchasing power of $\$10,000-\$25,000$?

Zero

19. What is the difference between the average per person purchasing power in the highest wealth country and the lowest wealth country?

About $\$41,000/\text{year}$

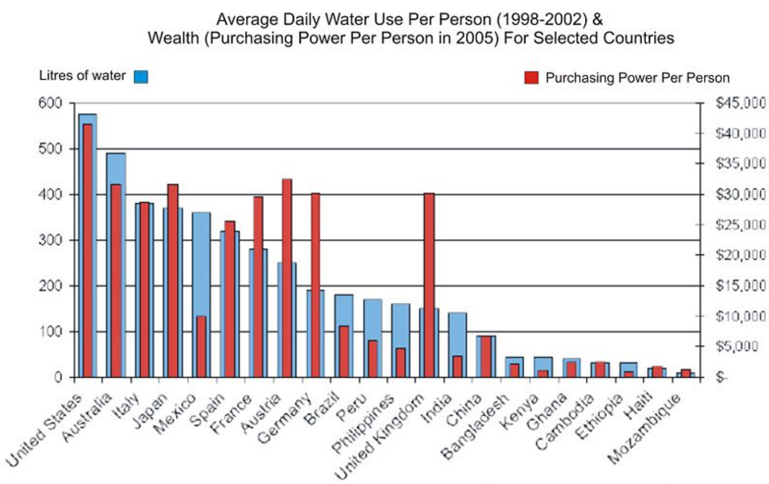


FIGURE 3.32

Average daily water use per person and wealth.

20. According to Figure 8, does there seem to be a relationship between a country's wealth and their average daily water consumption? If so, what is the relationship?

In most cases, with a few exceptions, the amount of wealth determines the amount of water consumption. In other words, the greater the wealth of a nation, the more water it consumes, and conversely, the less wealth a nation has, the less water it consumes.

Fine Filters Initial Ideas: Teacher Instructions

The goal of this exercise is to have your students "expose" their current ideas about the current and future availability of water on a global basis before they engage in learning activities that will explore these questions. You should let your students know that this is not a test of what they know and encourage them to make guesses which they will be able to evaluate based on what they learn in the unit. You may also want to have your students share their ideas with the class (there are no "bad" ideas at this stage) and create a giant class worksheet of ideas. Students can then discuss whether or not they think each of these statements is true and why.

Write down your initial ideas about each question below and then evaluate how confident you feel that each idea is true. At the end of the unit, we'll revisit this sheet and you'll get a chance to see if and how your ideas have changed.

TABLE 3.12:

1. What are water's unique properties so important for life as we know if?	How sure are you that this is true? Not sure	How sure are you that this is true? Kind-of-Sure	How sure are you that this is true? Very Sure	End of Unit Evaluation
2. How do we make water safe to drink?	**How sure are you that this is true?** Not sure	**How sure are you that this is true?** Kind-of-Sure	**How sure are you that this is true?** Very Sure	**End of Unit Evaluation**
3. How can nanotechnology help provide unique solutions to the water shortage?	**How sure are you that this is true?** Not sure	**How sure are you that this is true?** Kind-of-Sure	**How sure are you that this is true?** Very Sure	**End of Unit Evaluation**
4. Can we solve our global water shortage problems? Why or why not?	**How sure are you that this is true?** Not sure	**How sure are you that this is true?** Kind-of-Sure	**How sure are you that this is true?** Very Sure	**End of Unit Evaluation**

The Water Crisis: Quiz Answer Key

Write down your ideas about each question below.

1. What does it mean to have "clean fresh drinking water"?

Drinking water that does not contain salt or other contaminants that would be harmful to human health.

2. Explain the term "water scarcity."

Water scarcity means that there is not enough water to support water for drinking, industry, agriculture or environmental ecosystems.

3. Does water scarcity have an impact on human health? If so, what are some of the consequences?

Yes. In places of water scarcity, 80% of all child death under the age of five is related to diseases associated with a lack of clean water. Contaminated drinking water can cause severe diarrhea, a variety of other gastrointestinal disorders, and cause the accumulation of life disabling or fatal toxins in body tissues.

4. Describe three reasons why some nations are experiencing a scarcity of clean drinking water.

1. There is not enough physical water available to support a nation's needs for its population.
2. There is not enough money to deliver the water to the places that need it for drinking or for agriculture.
3. There is not enough money to clean the water to make it usable for drinking or for agriculture.

5. Why is the water scarcity problem projected to increase?

Water scarcity is projected to increase as population increases and puts more demands on water to meet the basic needs of people.

As underdeveloped countries become more industrialized, the trend is to consume more food that requires more water to produce.

6. Which sector—domestic, industrial, or agriculture—consumes the most water?

Agriculture.

The Science of Water

Contents

- Introduction to The Science of Water: Teacher Lesson Plan
- The Science of Water: PowerPoint with Teacher Notes
- The Science of Water Lab Activities: Teacher Instructions
- The Science of Water: Quiz Answer Key
- Reflecting on the Guiding Questions: Teacher Instructions

The Science of Water:Teacher Lesson Plan

Orientation

Water is one of the most unique and ubiquitous substances on our earth. Water's structure and properties account for many of the phenomena in our bodies and on our earth. This lesson reviews some of the science basics of water. If your students have not yet had a chemistry class, they may find some of this information overwhelming. These lessons are not intended to take the place of chemistry, where more intensive study is devoted to the variety of topics reviewed here.

- The Science of Water PowerPoint slide set introduces the structure of water that accounts for water's unique properties based on the quantum mechanical model of the atom, the shape of the water molecule and the distribution of charge.
- The Science of Water Lab Activities are set-up as lab stations. Their overall purpose is to give the students hands-on opportunities to experience some of the properties of water. Students may move through the stations throughout one or two periods, depending upon your schedule. You may also choose to eliminate one more of the stations to save time. Two of the stations are paper-pencil activities, and have no special requirements for lab equipment.
- The Reflecting on the Guiding Questions Worksheet asks students to connect their learning from the activities in the lesson to the driving questions of the unit.
- The Science of Water Student Quiz can be used as a formative or summative assessment of student learning through homework, an in-class group activity, or as an in-class individual assessment, depending on your goals.

Essential Questions (EQ)

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

(Numbers correspond to learning goals overview document)

1. Why are water's unique properties so important for life as we know it?

Enduring Understandings (EU)

Students will understand:

(Numbers correspond to learning goals overview document)

2. As a result of water's bent shape and polarity, water has unique properties, such as an ability to dissolve most substances. These properties are responsible for many important characteristics of nature.

Key Knowledge and Skills (KKS)

Students will be able to:

(Numbers correspond to learning goals overview document)

4. Describe the basic structure and charge distribution of water.

5. Explain how hydrogen bonding accounts for many of water's unique properties.

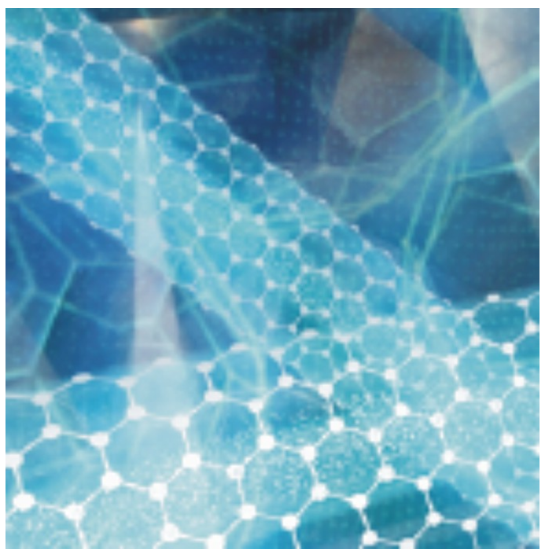
TABLE 3.13:

Day	Activity	Time	Materials
Day 1 (50 min)	Show the Science of Water PowerPoint Slides, using the question slides and teacher's notes to start class discussion.	50 min	The Science of Water PowerPoint Slides & Teacher Notes Computer and projector
Day 2 (50 min)	Students work in pairs or small groups at the Science of Water Lab Activities. Tell students to follow the posted directions to complete the lab at each station, moving to the next station when the current one is completed. Each student should complete their own Student Worksheet, although they may consult with other group members or the teacher.	50 min	The Science of Water Lab Activities: Student Directions posted at each Lab Station. Photocopies of the Science of Water: Student Worksheet
	Homework: Have students fill out the Reflecting on the Guiding Questions: Student Worksheet	10 min	Photocopies of Reflecting on the Guiding Questions: Student Worksheet
Day 3 (35 min)	Have students work in pairs or small groups to discuss their reflections on the Guiding Questions	10 min	Student's copies of their Reflecting on the Guiding Questions Worksheet

TABLE 3.13: (continued)

Day	Activity	Time	Materials
	Bring the class together to have students share their reflections with the class. This is also a good opportunity for you to address any misconceptions or incorrect assumptions from students that you have identified in the unit up till now.	10 min	
	Administer the Science of Water: Student Quiz during class, as an individual or group exercise, or as homework.	15 min	Photocopies of The Science of Water: Student Quiz

The Science of Water



We are surrounded by water; we are made of water

Water in our World

- Water is necessary for life
- Water in our atmosphere helps to keep the planet warm
- Our bodies are composed of and dependent on water

A Quick Overview

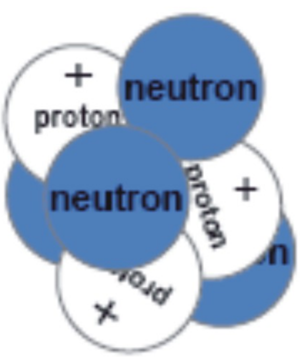
Of some of the science basics

What are some of the properties of water that make it so essential to life on our planet?

All Matter is Composed of Atoms

- The atom is composed of

FIGURE 3.33



Representation of a nucleus

FIGURE 3.34

- A nucleus made of neutrons and protons
- An electron "cloud" composed of electrons

- Protons and neutrons have nearly identical masses, but their charge is different
  - Protons have a positive (+) electrical charge and neutrons do not have an electrical charge

TABLE 3.14: Subatomic Particles Composing the Atom

Subatomic Particle	Charge	Size	Location
Proton	+1	1	Part of the nucleus
Neutron	0	1	Part of the nucleus
Electron	−1	0	Electron "cloud" (outside of the nucleus)

The Quantum Atom

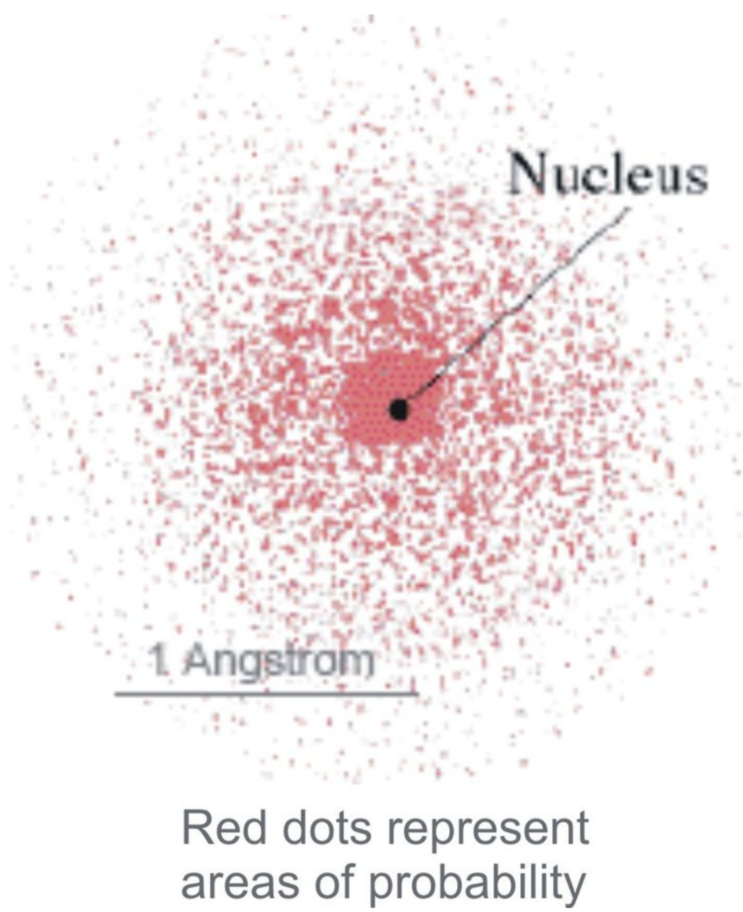


FIGURE 3.35

- We can only describe areas of probability where we might find an electron
  - Electrons are constantly moving
  - Electrons have a specific amount (quantum) of energy, related to their position from the nucleus

Probability

FIGURE 3.36

- Suppose you had a new dartboard. What would it look like after you had played darts with it for six months?
  - Can you predict accurately where the next dart you throw will go?
  - Can you predict an area where the next dart is likely to go?

Question

Why do we care about what atoms are made of?

Electric Charge

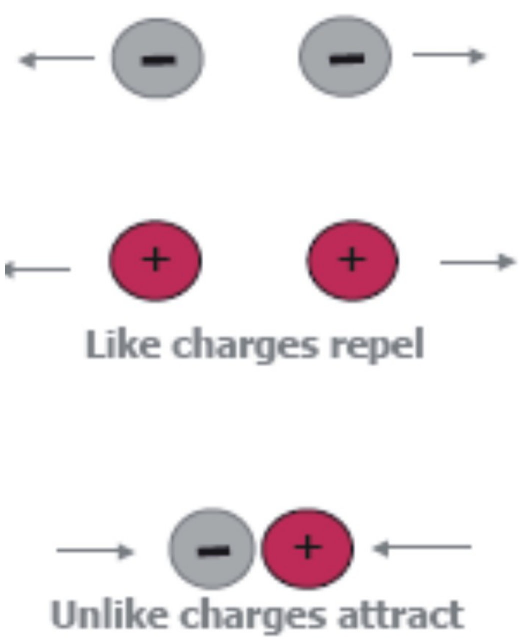


FIGURE 3.37

- Electric charge is a basic force that causes movement

Net Charge of an Atom or Ion

- The charge on any substance is a result of the total number (#) of
  - Protons (p) $\quad +$ charges, in the nucleus, and
  - Electrons (e^-) $\quad -$ charges, outside the nucleus
- If the # of... then the net charge is. . . .
  - $\mathrm{p} = \mathrm{e}^-$ $\quad$ neutral(atom)
  - $p > e^-$ $\quad$ positive(ion)
  - $e^- > p$ $\quad$ negative(ion)

Atoms Bond

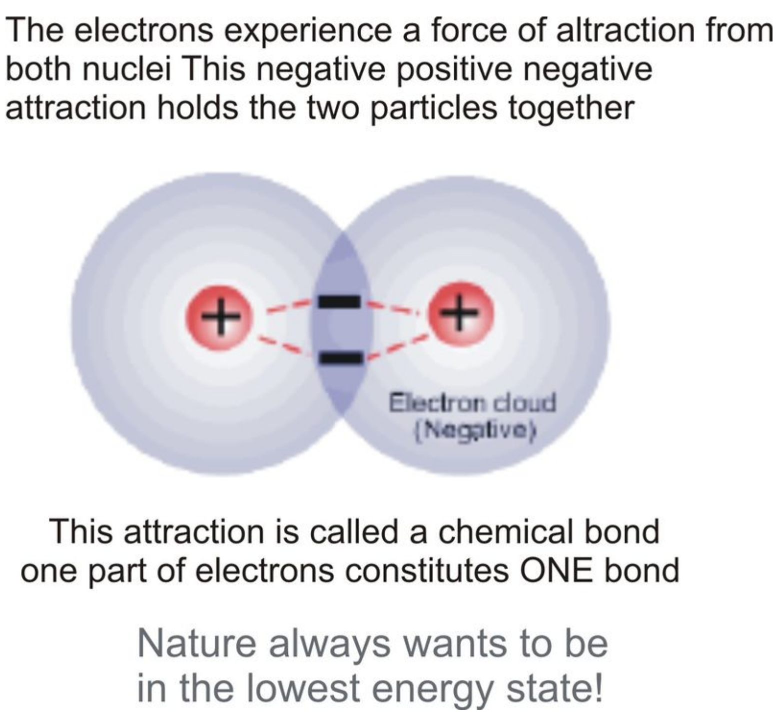


FIGURE 3.38

- The outer electrons of both atoms are mutually attracted to the nuclei
  - Oppositely charged particles form a bond, representing a lower energy state for each of the atoms, ***releasing energy***

Why are Bonds Formed?

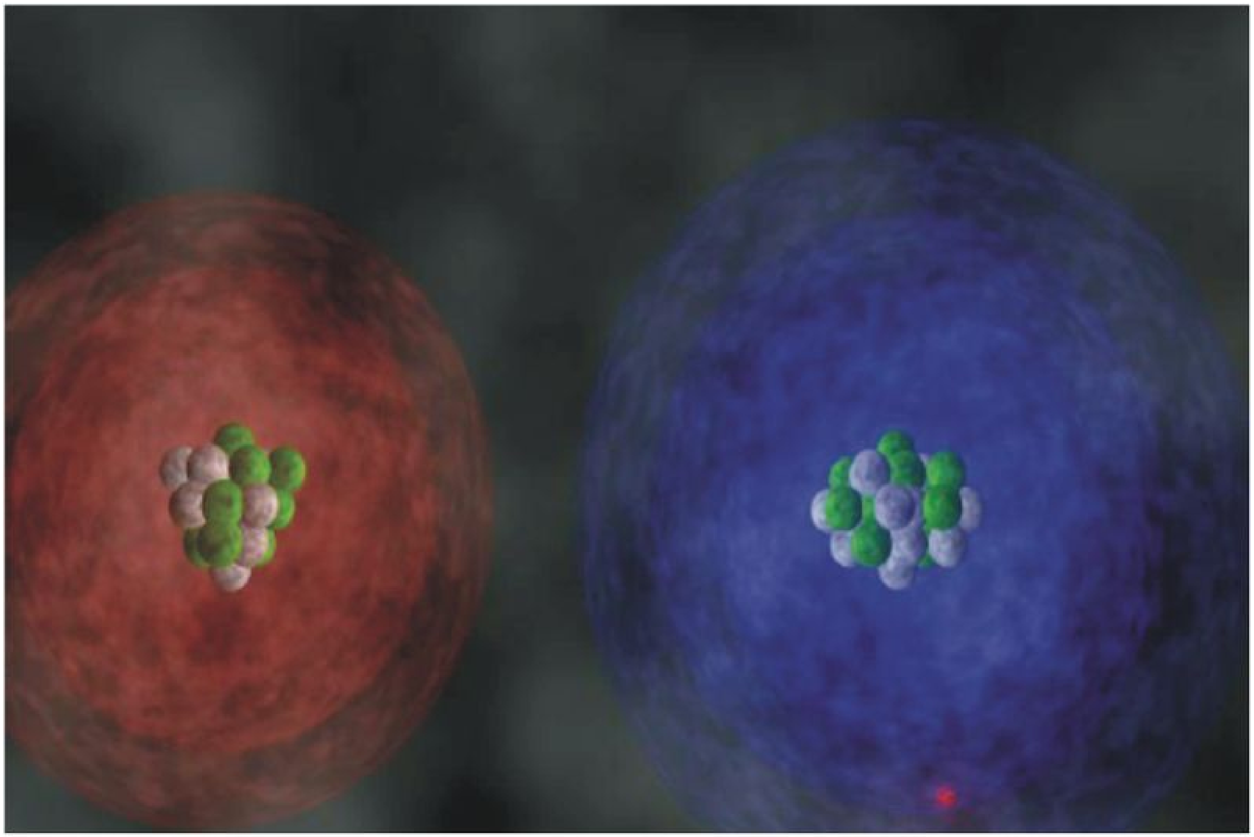
Bonds are formed because of the electrostatic attraction between atoms.

In doing so, the atoms achieve a lower energy state.

Ionic Bond: Chlorine (Blue) Grabs Electron from Sodium (Red)

Forming a Water Molecule

- Unequal attraction to bonding electrons
  - Oxygen is a strong electron grabber (high electronegativity)



Click the image above to view the animation in your web browser, or go to http://nanosense.org/download/finefilters/Nacl_SD.mov

FIGURE 3.39

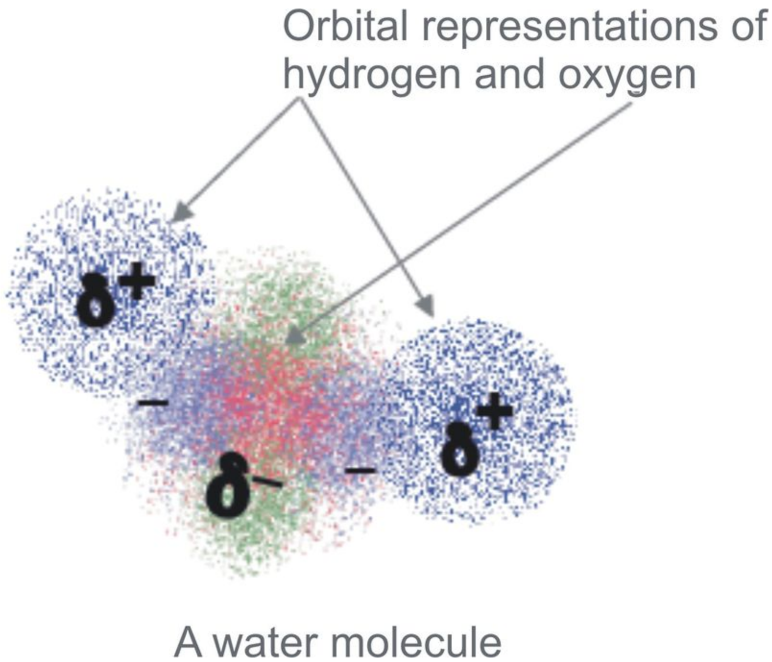


FIGURE 3.40

- Hydrogen's electron cloud tends to hang out close to oxygen, leaving H's positively charged nucleus all by itself

Electron Density is Uneven

- The average electron density around the oxygen atom in a water molecule is about 10 times greater than the density around the hydrogen atoms
  - This non-uniform distribution of positive and negative charges, called a dipole, leads to the substance's unusual behavior

Water is a Polar Molecule

- The unequal distribution of charges on the water molecule make it a *polar* molecule
  - One end is more negative, and one end is more positive

Hydrogen Bonding I

- The partial negative end of the oxygen atom is attracted to the partial positive end of the H atom on an adjacent molecule
- Hydrogen bonds give water its unique properties

Hydrogen Bonding II

Hydrogen Bonding Representation

- In water, hydrogen bonds form between the partially negatively charged oxygen atom and the partially positively charged hydrogen atom

Unique Properties of Water

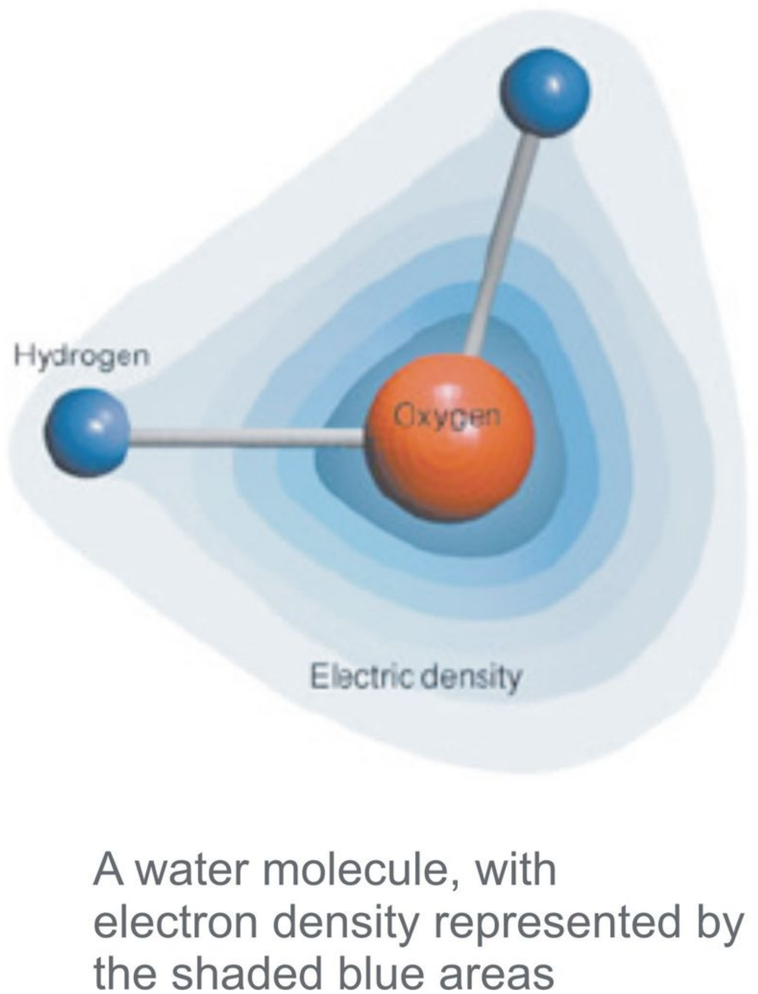

Hydrogen
Oxygen
Electric density
A water molecule, with electron density represented by the shaded blue areas

FIGURE 3.41

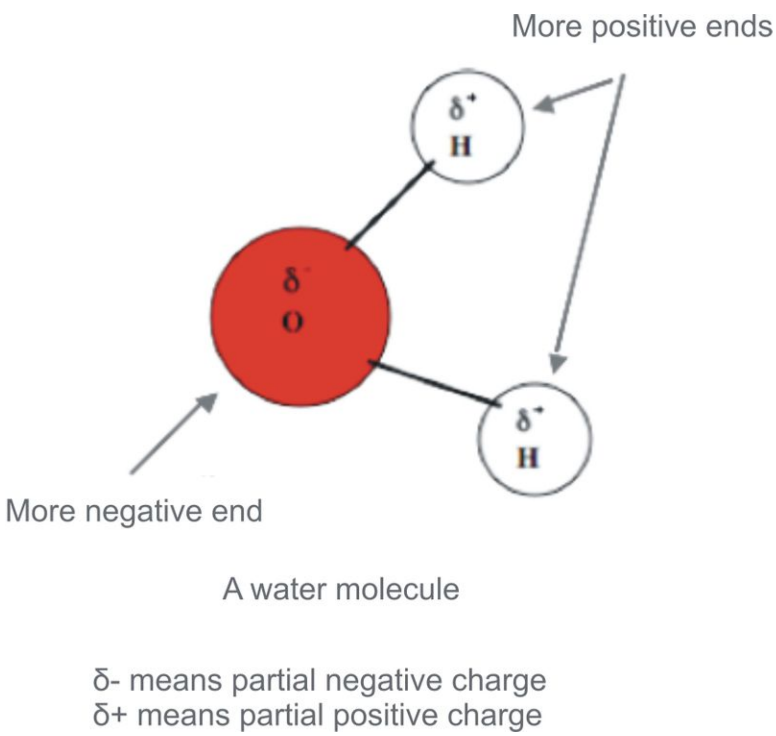


FIGURE 3.42

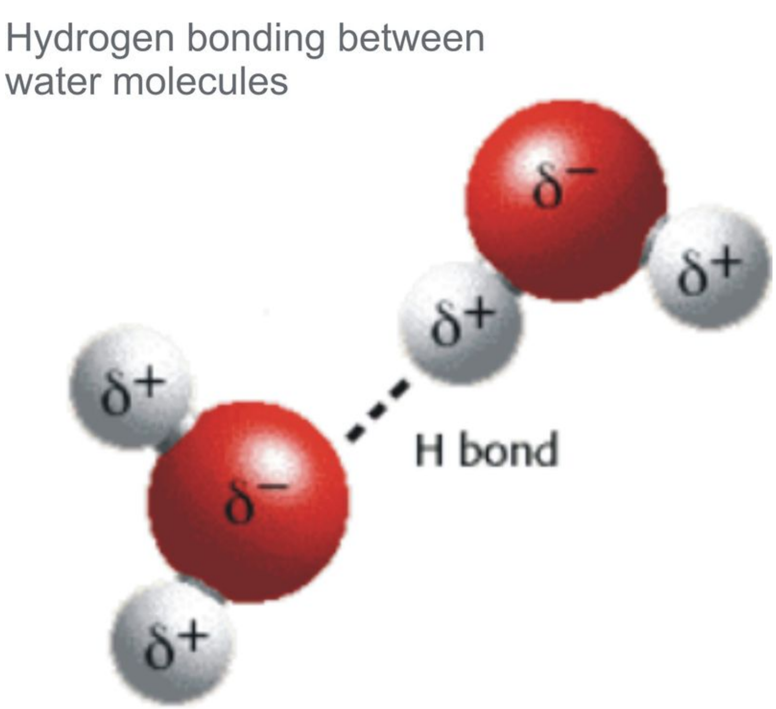


FIGURE 3.43

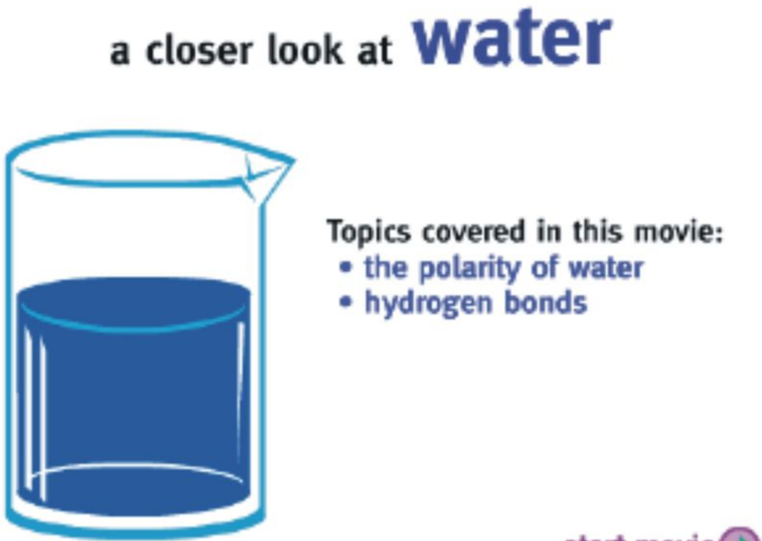


FIGURE 3.44

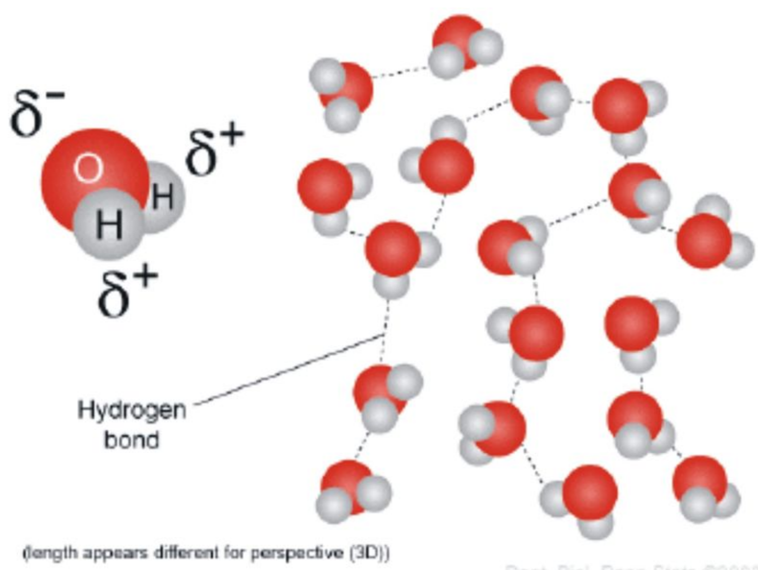


FIGURE 3.45

Water molecules, with the hydrogen bonds represented by the dotted lines

- Universal solvent
- Exists in nature as a solid, liquid, and gas
- The density of ice is less than liquid water
- High surface tension
- High heat capacity
- Exists as a liquid at room temperature

High Surface Tension

FIGURE 3.46

- Allows water to form drops
- Allows water to form waves
- Water drops can "adhere" to surfaces even though gravity is pulling on them

Can You Explain Why this Drop Sticks to the Leaf and Grows Larger?

Or How this Spider Can Walk on Water?

Adhesion

- Adhesive forces are attractive forces that occur between two unlike substances
- In a narrow glass tube
  - Water molecules are more strongly attracted to the tube than they are to each other (cohesion)
  - The cup shape formed at the top of the water is called a **meniscus**

Water Climbs Trees!

- Evapotranspiration
  - The tiny tubes in the root hairs suck up water from the soil
  - Inside the plant are more hollow tubes (xylem) for transporting water through the plant
  - Finally, water exits the plant through the tiny openings in its leaves (stomata)

High Specific Heat Keeps Beaches Cooler in the Day and Warmer at Night!

FIGURE 3.47

FIGURE 3.48

FIGURE 3.49

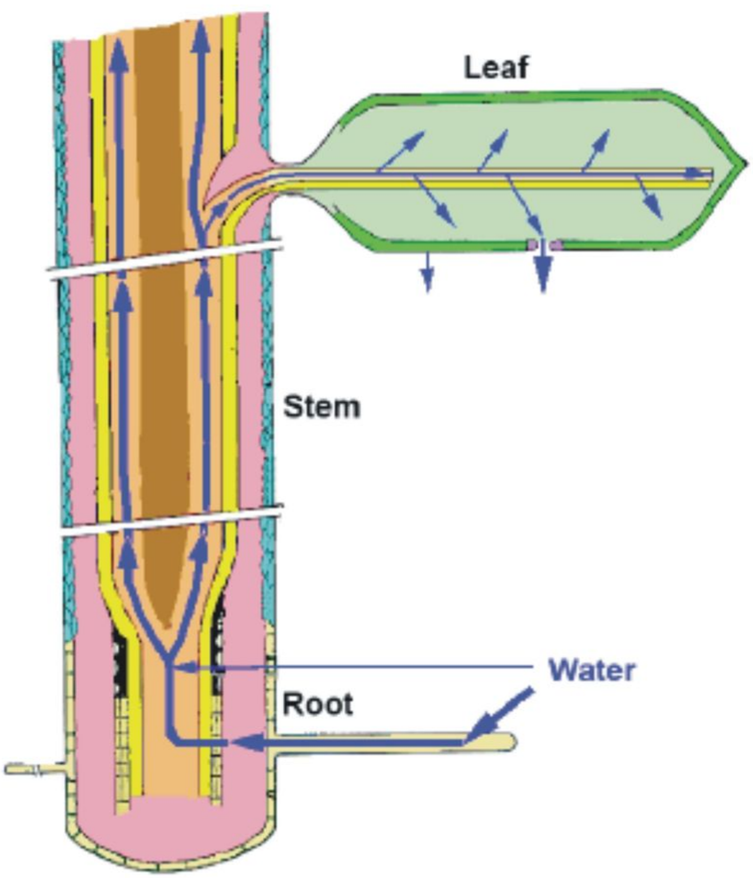


FIGURE 3.50

FIGURE 3.51

- Specific heat
  - The amount of energy required to change 1 gram of a substance 1°C
- Water has high specific heat
  - Absorbs large amounts of heat energy before it begins to get hot
  - Releases heat energy slowly
  - Moderates the Earth's climate and helps living organisms regulate their body temperature

Solid, Liquid, and Gas

- Water is the only substance which exists under normal conditions on earth as a solid, a liquid, and a gas

FIGURE 3.52

Ice is Less Dense than Water I

Density of H_2O at different temperatures

TABLE 3.15:

Temperature °C	Density g/cm^3
0 (solid)	0.9150
0 (liquid)	0.9999
4	1.0000
20	0.9982
100 (gas)	0.0006

Ice is Less Dense than Water II

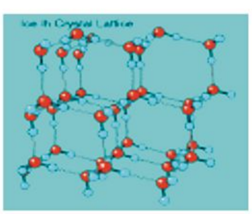
- This is a very rare property!

Questions

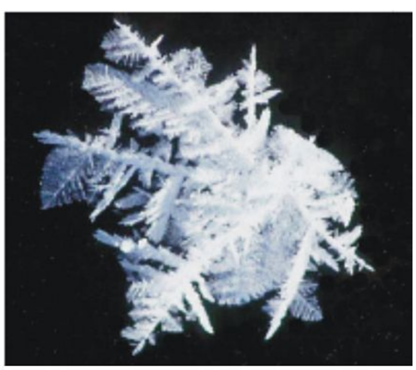
Can you imagine if ice did not float?

How do you think that would affect the world?

FIGURE 3.53



Crystal lattice structure of ice



Ice crystal

FIGURE 3.54

Ice Melting

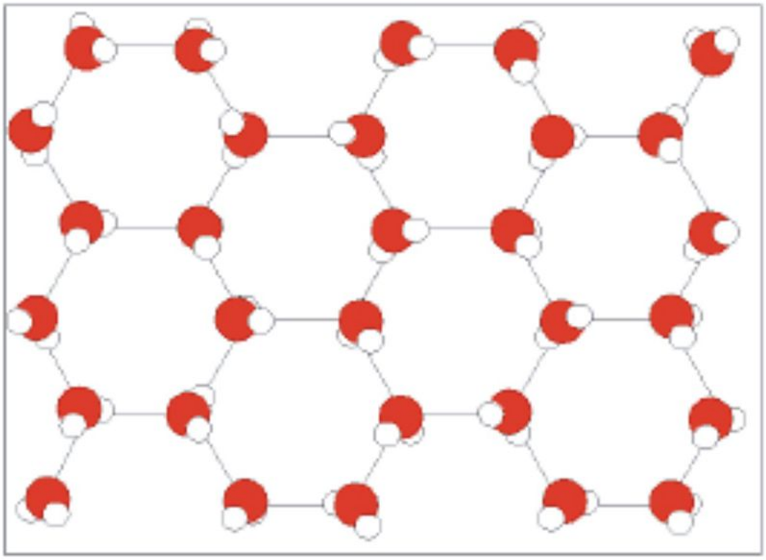


FIGURE 3.55

- Notice that ice has an open lattice structure that collapses when it melts

Water is a Universal Solvent

FIGURE 3.56

- Water is a polar molecule with one end more positive and one end more negative
  - Being polar allows water to dissolve nearly any substance with an unequal distribution of charges
  - Water is the best substance that is universally used for transporting dissolved substances

Important Points

- What are water's unique properties?
- What is water's structure, and how does it cause these properties?
- What would our world or life be like without water?

The Science of Water: Teacher Notes

Overview

This presentation gives students a sense of the structure of water in terms of its shape and charges. The traditions of science have been represented here to give students a picture of how modern science talks about the structure of atoms and charge distribution. Several representations of water are included in this slide set. The big "take away" for students is that hydrogen bonding creates stronger than normal (for substances of a similar molecular mass) bonds between water molecules. Those relatively strong bonds are the reason we see water's unusual properties: high surface tension, high boiling temperature, adhesion, cohesion, low vapor pressure, high specific heat, "universal solvent," the density of the solid form being less than that of the liquid form, and being a liquid at room temperature.

Students may have difficulty with some of the ideas represented in these slides, depending on their background. If students have a weak background in chemistry, it is suggested that the emphasis in these slides be on the shape and charge distribution of the water molecule as it relates to the above-mentioned properties of water.

Slide 1: The Science of Water

Ask students to think about where water is in this world, and what forms water comes in (solid, liquid, gas). Tell students that the focus of this lesson is on the special structure and characteristics of water that make it such a unique substance, a substance that we all depend upon for living.

Slide 2: Water in our World

Our planet is habitably warm because the sun's rays (electromagnetic radiation), filtered through the atmosphere, collide into the earth. When they reach the surface of the earth, the earth absorbs some of the rays, heating the earth. Some of the sun's rays are radiated back into the atmosphere as longer energy waves, infrared rays or heat. The gases in our atmosphere "trap" these energy waves, preventing them from escaping our atmosphere. The earth would be impossibly cold to live upon without this phenomenon, known as the "greenhouse" effect. Water is one of the greenhouse gases. There is much current concern over the amount of greenhouse gases entering the atmosphere and heating our planet to a growing degree. The emphasis of this attention has been mostly on the gases emitted from the combustion of fossil fuels, in other words, man's contribution to greenhouse gases as a result of using gasoline to fuel vehicles.

The human body is composed of water, among other substances. The total amount of water ranges from $50-80\%$, depending on age, amount of fat present, and other factors. The usual figure used for the amount of water in the normal adult body is 70% . Water is a major component of our blood, our lymph, our serous membranes, and other structures.

Slide 3: A Quick Overview

This set of slides presents a quick overview of the science of water. Each of the topics touched upon, such as models of the atom, bonding, charge distribution, physical properties, and chemical properties are big topics themselves. This set of slides is intended to present an overview only.

Discussion Question for Students: What are some of the properties of water that make it so essential to life on our planet?

You may want your students to brainstorm what they already know about water's unique properties. This is a good way to reveal students' prior knowledge and to uncover any misconceptions about the properties of water.

Slide 4: All Matter is Composed of Atoms

Most students have heard about the particles that compose the atom, as well as the basic structure. They probably will know that the nucleus, while being very, very small compared with the overall volume of an atom, comprises the mass of an atom. The neutron and proton are nearly identical masses compared with the negligible mass of an electron.

The purpose of this slide is to build knowledge about water's unique structure, starting from the basics, with an emphasis on the charge characteristics of a water molecule. The structure to emphasize in this slide is the positively charged nucleus (of a "generic" atom). This will determine the overall charge distribution as well as the net charge on atoms joined together to form molecules.

Slide 5: Subatomic Particles Composing the Atom

This chart represents a simplified version of the relative size, location, and charges of the proton, neutron, and electron.

For reference, a proton has a mass of 1.672×10^{-27} kg and a charge of $+1$, a neutron has a mass of 1.675×10^{-27} kg and no charge. An electron has a charge of -1 (the same magnitude as a proton's charge, but opposite in direction). The electron is described as having characteristics of a particle and a wave, depending upon the situation. (The photoelectric effect demonstrated by Einstein illustrates the particle behavior of an electron and Young's double slit experiment demonstrated an electron's wave behavior.)

All things point to the electron having no measurable size at this time, although our ability to measure incredibly small objects is limited.

Slide 6: The Quantum Atom

Again, the electron cloud representation as determined by quantum mechanics is shown here. The big points are:

1. The dots that represent the orbital cloud indicate a probability distribution of where an electron might be found. The more dense areas of the cloud represent areas of higher probability. The less dense, as depicted by the decreasing density of dots as one moves farther away from the nucleus, the less probability there is of finding an electron.
2. Electrons are constantly moving really, really fast. That means that the electric charge they carry is moving really, really fast as well. This overall or "net" electric charge distribution is what determines all bonding.
3. Electrons have a "quanta" of energy. Bohr learned that electrons could gain or lose only a specific quantum of energy. To illustrate this, think about a glass that you can fill with water, and stop filling at any position. Electrons are not like that. You may only "fill" by specific increments. These increments are individual to each electron in each atom. They can be measured when an electron "loses" energy by releasing a photon of light. This photon of light can be measured in terms of its wavelength, making it possible to determine its energy.

Slide 7: Probability

This slide is to help students to visualize the idea of a probability distribution in a more concrete way.

Slide 8: Question Slide

Questions for Students: What do students think? Why do we care about what atoms are made of?

This is another time that, within a class discussion, you may be afforded the opportunity to see what students understand and the discussion may allow any misconceptions to surface. Misconceptions are important to address, as they are very powerfully embedded in students' understanding of the world. They are resistant to being replaced with more accurate scientific information.

Slide 9: Electric Charge

Traditional curriculum underemphasizes the role of electric charge in chemistry. Often forces are addressed in physical science curriculum during middle school classes or in physics as an advanced course in high school. It is important for students to realize that these "swarms" of electrons represent an attractive (to positive charges) and repulsive (to negative charges) moving force. This is a very dynamic concept.

Slide 10: Net Charge of an Atom or Ion

This slide is to remind students that the net charge of an atom comes from the total amount of protons (positive charge) in the nucleus and the total amount of electrons (negative charge) in that atom. In addition to that, there may be an equal distribution of electric charge around some atoms, resulting in a polar molecule (a molecule that has a separation of charges).

Slide 11: Atoms Bond

This slide focuses on how opposite charges will form a bond and that a bond between two atoms represents a *lower energy state* for both of the atoms bonded together than if they were not bonded. Students may or may not know this. One of the laws of nature is that matter will always move to the lowest energy state possible. The lowest energy state is the most stable position for matter to obtain.

Slide 12: Why are Bonds Formed?

This slide highlights again that bonds are formed because of the attraction of oppositely charged particles. What causes atoms or particles to have opposite charges is not covered by this unit. That is another extensive subject that is beyond the scope of this slide set. This subject is a typical component in college preparatory chemistry.

Slide 13: Ionic Bond: Chlorine (Blue) Grabs Electron from Sodium (Red)

This is an animation that depicts a bond forming between sodium and chlorine. It is just to give students a sense of the swirling, moving electrons as the two atoms are held in close proximity. The video clip should play automatically when in the "view presentation" mode. If it does not play, click on the image to view the animation in your web browser.

Slide 14: Forming a Water Molecule

This is a depiction of the orbital representation of two hydrogen atoms and an oxygen atom, bonded, and their distribution of charges when they come together to form a water molecule.

The slide mentions "electronegativity." Electronegativity is a man-made composite value of the relative amount of each of the elements to attract an electron to itself. To obtain this value, several measures of each of the atoms are considered: first and second ionization energies, disassociation energy, and electron affinities. Linus Pauling was the first among many others to create this value. It has trends in the periodic table. Four is the highest electronegative number, assigned to fluorine, while one is the lowest.

To determine the type of bond that two atoms make, one must subtract the electronegative value of each atom. Though this is a continuum scale, if this difference is approximately 0.5 , the bond is considered a non-polar covalent. If the difference is between 0.5 and 1.6 (this varies), then the bond between the two atoms is a polar covalent one. If the difference in the electronegativity values of the two atoms is greater than 1.6 (or so) then the bond is an ionic bond.

Slide 15: Electron Density is Uneven

This slide depicts the density of the distribution of negative charges on the water molecule. This representation is somewhat controversial on the part of teachers. Some students expressed liking this representation, however, because it helped them to visualize an uneven distribution of electrons. The shaded area represents the strongest distribution of negative charges and the lighter areas represent the lower distribution of negative charges. The big point of this slide is to communicate the idea that on the water molecule there is a partial positive end and a partial negative end.

Slide 16: Water is a Polar Molecule

A more detailed picture of the water molecule further illustrates the previous slide. If students have not seen the symbol δ^+ (partial positive charge) and δ^- (partial negative charge), this would be a good time to explain these commonly used symbols.

Slide 17: Hydrogen Bonding I

Hydrogen bonding occurs in small molecules with a highly electronegative nonmetal element (N, Cl, O, F) that bonds with hydrogen. The attraction of hydrogen's lone electrons toward the highly electronegative atom results in a separation of charge on the molecule. Water is the most famous case of this. Hydrogen bonding occurs ***between*** adjacent molecules. While it is weaker than ionic or covalent bonding, which occurs between atoms to form molecules or ionic compounds, it is a stronger bond than Van der Walls forces that occur between adjacent molecules.

Slide 18: Hydrogen Bonding II

This is a clever animation that illustrates hydrogen bonding. If you have a hard time enabling the link embedded into this PowerPoint slide, try:

http://www.northland.cc.mn.us/biology/Biology1111/animations/hydrogenbonds.html

Slide 19: Hydrogen Bonding Representation

The water molecule in the center shows the partial positive and negative charges. The illustration on the right depicts these charges among several individual water molecules that are bonded (represented by the dotted line) negative end to positive end.

Slide 20: Unique Properties of Water

Although there are more unique properties of water, the ones listed on this slide are generally thought to be the most important. This slide will serve as an introduction to these properties. Each of these properties is explained further in the following slides.

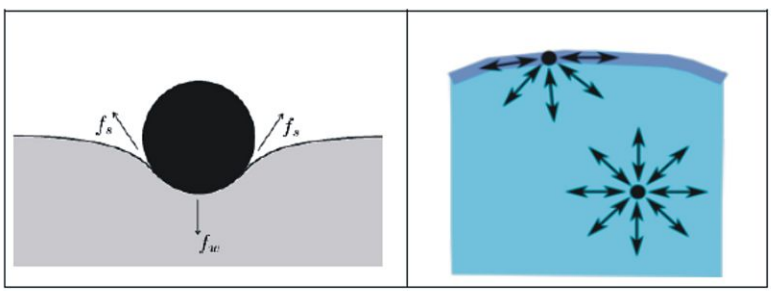


FIGURE 3.57

Surface of water with forces that prevent a particle from sinking *left* and forces of two water molecules *right*.

Slide 21: High Surface Tension

This slide introduces the concept of surface tension. One way of describing surface tension is to point out that sometimes water acts like a "skin." This results from the surface water molecules clinging to each other and NOT to the air molecules over them.

The images in Figure 1 above are two different representations of surface tension. The image on the left shows the surface of water with forces strong enough to prevent a particle from sinking. The image on the right shows the forces of two water molecules. The water molecule at the surface has fewer force arrows attracting it to the other water molecules than the water molecule below it that is surrounded on all sides by other water molecules.

Slide 22: Question Slide

Question for Students: Can you explain why this drop sticks to the leaf and grows larger?

Ask students to explain how water forms drops AND how water sticks to the leaf, instead of gravity pulling it down.

Slide 23: Question Slide

Question for Students: Or how this spider can walk on water?

The spider has very light feet that don't "puncture" the water. The water behaves like a skin, buoying up the spider.

Slide 24: Adhesion

Adhesion occurs when the water molecules are more attracted to the sides of a small diameter tube than they are to each other. This accounts for phenomena like the meniscus in tubular glassware, or for the capillary action that draws water up into the xylem (small tubes throughout a plant that transmit water) of a plant.

Slide 25: Water Climbs Trees!

The basis of water moving through plants is that, like a small graduated cylinder, water is more attracted to the sides of the plants than to other water molecules. The water climbs up the plants' tubes for transporting water (xylem), and the water molecules attach to each other, pulling them along as well (cohesion).

An additional assignment would be to have students use ChemSense (chemsense.org) to animate water molecules moving through a plant. Another would be to have students illustrate, at the molecular level, water moving through a plant.

Slide 26: High Specific Heat Keeps Beaches Cooler in the Day and Warmer at Night!

Definition: Specific heat is the amount of energy required to change 1 gram of a substance 1° Celsius.

Water has a relatively high specific heat. This means that it will absorb a lot of heat energy before raising the temperature of the water. If you live near a large body of water, the air temperature will not be as hot during the day. The water absorbs a lot of the heat, making air temperature milder than it is inland. When the sun goes down, the water slowly releases the heat that it has absorbed during the daytime. The night air temperature is warmer than the air inland. Climates are milder near large bodies of water than they are away from water.

Warm-blooded animals regulate their internal temperatures by being composed of large amounts of water. This water is slow to heat and slow to cool, moderating temperatures from outside of the body to inside the body. During periods of extreme heat, animals can release heat by sweating. The sweat on the outside of the skin absorbs energy as it evaporates off of the skin, cooling the temperature of the skin beneath the sweat.

Slide 27: Solid, Liquid, and Gas

Have students think about any other substance that is found naturally on earth in more than one phase of matter. Water is the only one to exist naturally in all three phases.

Slide 28: Ice is Less Dense than Water I

This table illustrates that water is the most dense at $4°C$. Have students examine the figures for the density of water at different temperatures.

Slide 29: Ice is Less Dense than Water II

This slide is just a visual to illustrate a macro-picture of an ice crystal and a nano-picture of ice as a solid. The crystal lattice structure of ice literally expands the structure of water as a solid, which will then collapse and become denser when melted.

Slide 30: Question Slide

Questions for Students: Can you imagine if ice did not float? How do you think that would affect the world?

Slide 31: Ice Melting

Click on the image to view the animation in your web browser. This will show the water molecules losing the bonds between them, collapsing and moving faster as the phase changes from solid to liquid.

Slide 32: Water is a Universal Solvent

Water is often described as a universal solvent. This is not really accurate. Water can dissolve polar or ionic substances. Water cannot dissolve nonpolar substances. Water's positive end and negative end have nothing to be differentially attracted to in a nonpolar substance. Water also cannot dissolve ionic substances that are more attracted to each other than they are to the overall force of the water molecules that surround the ions. This process of dissolving is known as solvation.

Slide 33: Important Points

Have students discuss these questions and review the important concepts presented in this lesson.

The Science of Water Lab Activities: Teacher Instructions

Overview

There are three sets of curricular materials for these labs:

1. **The Science of Water 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 each station.
2. **The Science of Water 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 students to follow.
3. **The Science of Water 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 water a unique substance.

Each of the following labs is designed to demonstrate a specific aspect of the unique chemistry of water. The lab is set up at multiple stations. Each student or group of students will conduct investigations at each station.

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. No dangerous substances are recommended for this lab.

The lab stations are:

- Lab Station A: Surface Tension Lab
- Lab Station B: Adhesion/Cohesion Lab
- Lab Station C: Can You Take the Heat?
- Lab Station D: Liquid at Room Temperature Data Activity
- Lab Station E: Now You See It, Now You Don't, A Dissolving Lab
- Lab Station F: Predict a New World! Inquiry Activity

Materials

A complete list of materials can be found at the end of the set of teacher instructions.

Time Duration

Although the set of laboratory experiences is designed to occupy an entire class period, each lab will vary in the time that it takes to complete. If time is short, you may have students share their data with each other at the end of the class period. Also Lab Stations D and F are paper and pencil labs. You may want to assign these to students as homework or as a warm-up rather than as a separate lab station.

Lab Station A: Surface Tension Lab

Purpose

The purpose of this lab is to investigate the property of the surface tension of water. This lab will look at the way that water sticks to itself to make a rounded shape, the way that water behaves as a "skin" at the surface, and a comparison of water's surface tension with two other liquids, oil and soapy water.

Safety Precautions

- Wearing goggles is dependent on your school's safety criteria.
- Caution needs to be exercised around hot plates and the alcohol burner.
- Caution needs to be exercised around hot water and hot glassware.
- Do not eat or drink anything in the lab.
- Do not wear open-toed sandals in the lab.
- Wear long hair tied back to prevent touching the substances at the lab stations.

Materials

- 3 pennies
- Available water
- Small containers of water, oil, and soapy water
- A dropper for each of the containers
- A square, about 4" $\times$ 4" , of wax paper

Procedures

Counting Drops on a Penny

1. Check to make sure all of the materials needed are at your lab station.
2. Using a dropper bottle containing only water, count the number of drops of water that you can balance on top of a penny. When the water falls off of the penny, record the number of drops. Wipe the water off of the penny.
3. Repeat this procedure of counting and recording drops with oil and then with the soapy water.

Comparing the Shape of a Drop

1. Drop a small sample of each of the liquids—water, oil, and soapy water—on the wax paper. Draw the shape and label the shape of the drops made by each of the liquids on your worksheet. Wipe off the wax paper.
2. Answer the questions on your worksheet.

Lab Station B: Adhesion/Cohesion Lab

Purpose

The purpose of this lab is to investigate the property of **cohesion** and **adhesion** of water.

- **Cohesion** is the molecular attraction exerted between molecules that are the same, such as water molecules.
- **Adhesion** is the molecular attraction exerted between unlike substances in contact.

Cohesion causes water to form drops, surface tension causes them to be nearly spherical, and adhesion keeps the drops in place (http://en.wikipedia.org/wiki/Adhesion).

This lab will work with capillary tubing of various diameters to see the rate at which water is able to "climb" up the tubes. This is very similar to the way that water enters a plant and travels upward in the small tubes throughout the plant's body. The "stickiness" of the water molecule allows the water to cling to the surface of the inside of the tubes.

You will see how the diameter of the tube correlates with the rate of traveling up the tube by measuring how high the dye-colored water column is at the end of the time intervals.

Safety Precautions

- COOL GLASSWARE FOR A FEW MINUTES BEFORE PUTTING INTO THE COOLING BATH OR THE GLASSWARE WILL BREAK.
- Wearing goggles is dependent on your school's safety criterion.

- Do not eat or drink anything in the lab.
- Do not wear open-toed sandals in the lab.
- Wear long hair tied back.

Materials

- 4 pieces of capillary tubing of varying small sized diameters (no greater than 7 mm in diameter), 8 – 24 inches in length
- Metric ruler
- Pan of dyed (with food coloring) water into which to set the capillary tubing
- Clamps on ring stands to stabilize the tubing so that it remains upright in a straight position

Procedures

1. Check to make sure all of the materials needed are at your lab station.
2. Set the capillary tubing into the dye-colored water from the largest diameter tubing to the smallest. Make certain they are all upright and secure.
3. Record the height of each of the tubes in the table on your worksheet every 2 minutes .
4. After 10 minutes , release the capillary tubing, wrap the tubing in paper towels, and deposit them in an area designated by your teacher.
5. Answer the questions about this experiment on your lab sheet.

Teacher Notes

Try to obtain five different diameters of tubing. These are available through many different suppliers.

Lab Station C: Can You Take the Heat?

Purpose

The purpose of this lab is to investigate the heat capacity of water. You will measure the temperature of water (specific heat of water is 4.19 kJ/kg.K) and vegetable oil (specific heat of vegetable oil is 1.67 kJ/kg.K) over equal intervals of time, and will record your data and findings on your lab sheet.

Specific heat is the amount of energy required to raise 1.0 gram of a substance $1.0°C$.

Safety Precautions

- Cool hot glassware slowly. Wait a few minutes before placing in cold water or the glass will break.
- Wearing goggles is dependent on your school's safety criterion.
- Do not eat or drink anything in the lab.
- Do not wear open-toed sandals in the lab.
- Wear long hair tied back.
- Use caution when working with fire or heat. Do not touch hot glassware.

Materials

Assemble two Erlenmeyer flasks or beakers, each containing one of the liquids, with a thermometer held by a thermometer clamp that is to be inserted about midway into the liquid.

- 2 equal amounts, about 100 – mL , of water and vegetable oil
- 2 250 – mL Erlenmeyer flasks or 2 250 – mL beakers
- 2 thermometers
- 2 Bunsen burners or 1-2 hot plates
- 2 ring stands: each ring stand will have a clamp to hold the thermometer. Use a screen if using a Bunsen burner rather than hot plate(s).

- Cold water bath for cooling the Erlenmeyer flasks or beakers

Procedures

1. Set the cooled flasks containing their solutions on the ring stands or hot plate.

2. Take the initial temperature reading of each of the liquids.

3. Turn on the hot plate to a medium temperature, or, if using Bunsen burners instead, light them, adjusting the flame of each to the same level.

4. Record the temperature of the liquid in each flask every 2 minutes until 4 minutes after each liquid boils. Record the temperature in the table on your lab sheet.

5. After recording the final temperatures, move the Erlenmeyer flasks or beakers with tongs or a heat-resistant set of gloves into the cooling bath. Add small amounts of ice as needed to keep the water temperature cold.

DO NOT THRUST HOT GLASSWARE DIRECTLY INTO ICY WATER BEFORE COOLING BECAUSE THE GLASS WILL BREAK!

6. Answer the questions about this experiment on your lab sheet.

Lab Station D: Liquid at Room Temperature Data Activity

Purpose

The purpose of this activity is to discover how unusual it is, based on a substance's molecular weight, that water is a liquid at room temperature.

Safety Precautions

None are needed, since this is a paper and pencil activity.

Materials

- Water is Weird! Data Table
- Lab worksheet for recording trends

Procedures

Data Table 1 shows the physical properties of a variety of substances. This table is typical of one that a chemist would examine to look for trends in the data. For instance, is there any correlation with the color of the substance and its state of matter? Is there any correlation between the state-of-matter of a substance and its density? How does water compare to other substances?

1. Examine the data table. Look for relationships between the physical properties of some of these substances.
2. Discuss the trends with your lab partner. Record your thoughts on your lab worksheet.
3. Answer the questions about this experiment on your lab worksheet.

Teacher Notes

If you are short of time, this activity can be done as homework or as a warm-up assignment. If you need extra lab station space, this activity can be conducted at the students' desks.

Water is Weird! Data Analysis Activity

Water is Weird! How Do We Know?

We have been discussing the many ways that water is weird. Water seems pretty common to us. How do we know that it is unusual? Let's compare water to some other substances and see what we can find, using the data table below.

Record the trends that you notice on your lab worksheet.

TABLE 3.16: Physical Properties of Some Substances

Substance	Formula	Molar mass, grams	State of matter at normal room conditions	Color	Specific Heat J/gK	Density of gas, liquid, or solid	Boiling Temperature, ^oC
Water	H_2O	18.0	liquid	colorless	4.19	$0.997\,g/cm^3$	100
Methane	CH_4	16.0	gas	colorless		$0.423^{-162}\,g/cm^3$	-161.5
Ammonia	NH_3	17.0	gas	colorless		$0.701.308\,g/L$	-33
Propane	C_3H_8	44.1	gas	colorless		$0.493^{25}\,g/cm^3$	-42.1
Oxygen	O_2	32.0	gas	colorless	0.92	$1.308\,g/L$	-182.9
Carbon dioxide	CO_2	44.0	gas	colorless		$1.799\,g/L$	-78.5
Bromine	Br_2	159.8	liquid	red	0.47	4.04	58.8
Lithium	Li	6.94	solid	silvery, white metal	3.58	$0.534\,g/cm^3$	1342
Magnesium	Mg	24.3	solid	silvery, white metal	1.02	$1.74\,g/cm^3$	1090

Lab Station E: Now You See It, Now You Don't A Dissolving Lab

Purpose

The purpose of this activity is to introduce the idea that different types of liquids may dissolve different substances.

Safety Precautions

- Wearing goggles is dependent on your school's safety criterion.
- Do not eat or drink anything in the lab.
- Do not wear open-toed shoes.
- Tie long hair back.

Materials

- 6 plastic cups
- 6 plastic spoons
- Water
- Oil
- Granulated salt
- Granulated sugar
- Iodine crystals

Procedures

1. Fill 3 plastic cups $1/3$ to $1/2$ full with water.
2. Fill 3 plastic cups $1/3$ to $1/2$ full with oil.
3. Put about a half-teaspoon of salt into the water in one cup and another half-teaspoon of salt into the oil in one cup.
4. Stir each for about 20 seconds or until dissolved.
5. Record your observations in the table on your lab sheet.
6. Repeat this procedure with sugar.
7. Repeat this procedure using iodine crystals BUT only drop 2 or 3 crystals into the water and into the oil.

8. Record your observations and answer the questions about this experiment on your lab sheet.

Lab Station F: Predict a New World! Inquiry Activity

Purpose

We all know that ice floats; we take it for granted. However, in nature, the solid form of a substance being less dense than the liquid form is extraordinary. What we don't know or think about much is how our world would be affected if ice did not float in water. This "thought" activity explores the worldly implications if ice had a greater density than water.

Safety Precautions

None are required because this is a paper and pencil activity.

Materials

- Place a fish bowl with some fish and live plants at this station

Procedures

1. Read the following. Look at the fish bowl. Think. Write your thoughts on your lab worksheet.

Assume that there will be one change in the way that nature behaves: On the day after tomorrow, worldwide, ice (the solid form of water) will now become denser than water, rather than its current state, which is less dense.

What will be the impact of this change?

FIGURE 3.58

Beautiful lake in early winter.

1

2. Discuss this with your lab partner.

3. Answer the questions about this experiment on your lab worksheet.

Reference

- http://snow.reports.co.nz/snow_ida_800.jpg

Teacher Notes

This assignment can be homework assigned before this lesson, if there is not sufficient time to do this as a lab activity, or if you prefer.

Materials List

- 3 pennies
- Available water
- Small containers of water, oil, and soapy water, and a dropper for each
- A square, about 4” $\times$ 4” , of wax paper
- Hot plate
- Thermometer
- Ice water (without the ice)
- 4 pieces of $8-24$ inches of capillary tubing of varying small sized dimensions, no greater than 7 mm
- Metric ruler
- Pan of dyed (with food coloring) water into which to set the capillary tubing
- Clamps on stands that will stabilize the tubing to remain upright in a straight position
- 2 equal amounts, about $100-$ mL , of water and vegetable oil
- 2 $250-$ mL Erlenmeyer flasks or beakers
- 2 thermometers
- 2 Bunsen burners or a hot plate
- 2 ring stands, with screens if needed, to hold Erlenmeyer flasks or beakers
- 2 additional clamps to hold the thermometers in place
- Cold water bath for cooling the Erlenmeyer flasks
- 6 plastic cups
- 6 plastic spoons
- Water at room temperature
- Oil at room temperature
- Granulated salt
- Granulated sugar
- Iodine crystals
- A timer with a second hand
- Glassware tongs or heat resistant mitts
- $100-$ mL graduated cylinder

The Science of Water: Quiz Answer Key

Write down your ideas about each question below.

1. Why does all bonding occur between atoms, ions, and molecules?

All bonding occurs because of the attraction of opposite charges.

2. Draw a water molecule. Label the atoms that make up the water molecule with their chemical symbol. If there is an electrical charge or a partial electrical charge on any of the atoms, indicate that by writing the symbols on the atoms:

$+$ = positive charge	$-$ = negative charge
δ^+ = partial positive charge	δ^- = partial negative charge

3. Explain the term “polar” molecule.

A polar molecule has a more positive end and a more negative end. These can be permanent or they can be temporary.

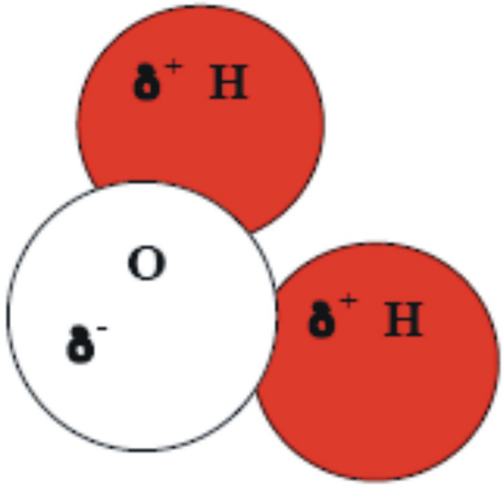


FIGURE 3.59

4. Why does water have an increased surface tension compared to most other liquids?

A water molecule has a greater surface tension relative to other liquids because the water molecules are more strongly attracted to the other water molecules surrounding them on all sides, as compared with the water molecules at the surface, which are surrounded by air (mostly nitrogen and oxygen gases). Water is not attracted to air molecules.

5. What is "hydrogen bonding"? What makes these bonds unique?

Hydrogen bonding is the bonding that occurs between adjacent water molecules. (Alhough our focus is on water, there are other molecules that exhibit hydrogen bonding as well as water.) The positive end of one water molecule is attracted to the negative end of the next water molecule. This is why water is a liquid at room temperature. A definition of hydrogen bonding is: The attraction of one end of a small, highly electronegative nonmetal atom in a molecule to the hydrogen end, more electropositive, end of an adjacent molecule.

6. a. Define or describe "specific heat."

Specific heat is the amount of energy required to raise 1.0 gram of a substance $1.0°C$.

b. How does water's specific heat have an impact on our climate?

The temperature of the air near large bodies of water is more moderate than the temperature of air that is not near a large body of water. For instance, for cities bordering the ocean, the ocean absorbs heat during the day, making air temperatures cooler than they would be inland. At night, the ocean slowly releases the heat absorbed during the day, making the air temperatures warmer than they are inland.

7. Is water's specific heat, compared to other liquids:

High ⊠ or Average □ or Low □

8. Are water's melting and boiling temperatures, compared to other liquids:

High ⊠ or Average □ or Low □

9. a. What happens to the temperature of the water in a pot on a heated stove as it continues to boil?

The temperature of the water stays at $100°C$ during boiling.

b. Explain what the energy is being used for that is heating the water at the boiling temperature.

The heat energy being continually added to a pot of water during boiling is used to break the bonds of attraction (hydrogen bonding) between water molecules, so that each individual water molecule may change from the liquid phase to the gas phase.

10. Explain how a spider can walk on water.

The surface tension of the water is greater than the pull of the gravity on the spider's little feet.

11. Fill out the following table: Name and explain five of water's unique properties, and provide an example of the phenomenon in nature caused by each of these properties.

TABLE 3.17:

Property of Water	Explanation of Property	Phenomenon Property Causes
High boiling temperature	It takes a relatively large amount of energy to boil water compared with other small nonmetal liquids.	Water at sea level must reach $100°C$ before it will boil.
High surface tension	The surface of water acts like a "skin."	Spiders can walk on water.
High specific heat	Water absorbs a relatively large amount of energy to raise its temperature $1°C$.	Climate near large bodies of water is moderate compared with climate further away from large bodies of water.
Solid is less dense than liquid	Water expands in volume when frozen.	Ice floats rather than sinks.
Universal solvent	Water dissolves positive and negatively charged particles.	Water is not found "pure" in nature because it dissolves so much of what it comes into contact with.

Reflecting on the Guiding Questions: Teacher Instructions

You may want to have your students keep these in a folder to use at the end of the unit, or collect them to see how your students' thinking is progressing.

Think about the activity you just completed. What did you learn that will help you answer the guiding questions? Jot down notes in the spaces below.

1. Why are water's unique properties so important for life as we know it?

What I learned in these activities:

What I still want to know:

2. How do we make water safe to drink?

What I learned in these activities:

What I still want to know:

3. How can nanotechnology help provide unique solutions to the water shortage?

What I learned in these activities:

What I still want to know:

4. Can we solve our global water shortage problems? Why or why not?

What I learned in these activities:

What I still want to know:

Nanofiltration

Contents

- Nanofiltration: Teacher Lesson Plan
- Nanofiltration: Teacher Reading
- Nanofiltration: PowerPoint with Teacher Notes
- Which Method is Best? Answer Key
- Comparing Nanofilters to Conventional Filters Lab Activity: Teacher Instructions
- Cleaning Jarny's Water: Teacher Instructions #38; Rubric
- Reflecting on the Guiding Questions: Teacher Instructions

Teacher Lesson Plan

Orientation

As a dynamic, evolving area of science, nanotechnology can provide an exciting learning opportunity for students, offering them the opportunity to learn about current science and technology innovations that may improve our world. The use of nanofiltration for cleaning water is one such innovation. Scientists are working to develop newer, cheaper and more effective membrane technologies to clean water. Much of the current work has focused on new designs of nanofilters, and nanofiltration systems are currently deployed in a few metropolitan areas.

Learning about nanofiltration also reinforces important fundamental chemistry concepts that are sometimes difficult for students to grasp. Students must understand differences in solution types to understand how different filtration systems work on a small scale. The topic of nanofiltration also has the potential to help students see interdisciplinary connections between biology, chemistry, and engineering.

The lessons in the Fine Filters unit focus conceptually on the role of membrane technology for filtering water. The presentation, notes, activities and readings focus on key aspects of filtration such as underlying technologies, particle filtration sizes, and applications.

- The Nanofiltration Teacher and Student Readings provide background on how nanofiltration works. The teacher reading is recommended prior to presenting the Nanofiltration PowerPoint slides and other activities.
- The Nanofiltration PowerPoint slide set provides a brief introduction to the different types of filtration and how they work, with emphasis on nanofiltration methods.
- The Which Method is Best exercise is a worksheet activity that allows students to explore some of the basic ideas of filtration, such as membranes and particle size, and prepares them for the more involved lab activity.
- The Comparing Nanofilters to Conventional Filters lab activity gives students a hands-on opportunity to better understand two types of filtration.
- The Cleaning Jarny's Water exercise allows students to explore ideas of filtration in a real-world application.
- The New Nano-Membranes Reading introduces students to current research in creating nanotechnology membranes
- The Reflecting on the Guiding Questions Worksheet asks students to connect their learning from the activities in the lesson to the driving questions of the unit.

Essential Questions (EQ)

What essential question(s) will guide this unit and focus teaching and learning?

(Numbers correspond to learning goals overview document)

2. How do we make water safe to drink?

3. How can nanotechnology help provide unique solutions to the water shortage?

Enduring Understandings (EU)

Students will understand:

(Numbers correspond to learning goals overview document)

3. Pollutants can be separated from water using a variety of filtration methods. The smaller the particle that is to be separated from a solution, the smaller the required pore size of the filter and the higher the cost of the process.

4. Innovations using nanotechnology to create a new generation of membranes for water filtration are designed to solve some critical problems in a cost-effective way that allows for widespread use.

Key Knowledge and Skills (KKS)

Students will be able to:

(Numbers correspond to learning goals overview document)

2. Describe different types of filtration in terms of the pore size of the filter, substances it can separate, and cost of use.

3. Use laboratory procedures to compare the relative effectiveness of different filtration methods on particle separation.

TABLE 3.18:

Day	Activity	Time	Materials
	Homework: Nanofiltration: Student Reading	20 min	Photocopies of Nanofiltration: Student Reading
Day 1 (50 min)	Show the Nanofiltration PowerPoint slides, using the teacher's notes to start class discussion.	30 min	Nanofiltration PowerPoint Slides & Teacher Notes Computer and projector
	Hand out the Which Method is Best? Student Worksheet and The Filtration Spectrum: Student Handout and have students work in small groups to answer the questions.	10 min	Photocopies of Which Method is Best? Student Worksheet Photocopies of The Filtration Spectrum: Student Handout

TABLE 3.18: (continued)

Day	Activity	Time	Materials
	Return to whole class discussion and have students share their ideas on which types of membrane can filter which type of particles. You may want to have different students each draw a particular membrane and related filtrated particles to help drive class discussion. This activity is a preparation exercise for the lab that will take place on day 2 of this lesson. Pre-read the lab and give students an indication of what to expect during the next class session.	10 min	Comparing Nanofilters to Conventional Filters Lab Activity: Teacher Instructions
	Homework: Read the Comparing Nanofilters to Conventional Filter Lab Activity: Student Instructions in preparation for the next class.	25 min	Photocopies of the Comparing Nanofilters to Conventional Filters Lab Activity: Student Instructions
Day 2 (50 min)	Have students work in pairs or small groups on the Comparing Nanofilters to Conventional Filters Lab Activity. Each student should complete their own Student Worksheet, although they may consult with other group members or the teacher.	50 min	Photocopies of the Comparing Nanofilters to Conventional Filters Lab Activity: Student Worksheet
	Homework: New Nano-Membranes: Student Reading	15 min	Photocopies of New Nano-Membranes: Student Reading
Day 3 (50 min)	Have students work on the Cleaning Jarny's Water activity in small groups.	25 min	Photocopies of Cleaning Jarny's Water: Student Instructions & Report
	Have students discuss the New Nano-Membranes: Student Reading in small groups.	10 min	Photocopies of the New Nano-Membranes: Student Reading

TABLE 3.18: (continued)

Day	Activity	Time	Materials
	Have students work individually or in small groups to fill out the Reflecting on the Guiding Questions: Student Worksheet.	10 min	Photocopies of Reflecting on the Guiding Questions: Student Worksheet
	Discuss the Essential Questions and the group's collective ability to answer them based on the work done in the unit and answer any remaining student questions.	5 min	

Teacher Reading

How is Water Cleaned?

Water cleansing is complex. There are many methods for making water safe to drink. In addition, new technologies are being researched and patented at a relatively rapid rate. Typically, water is cleaned through multi-step processes that balance efficacy (i.e. contaminant removal) with cost-effectiveness.

Non-Filtration Techniques

While filtration is the main technique used to clean water, there are several common methods of cleaning water that are used independently and/or in addition to filtration.

- **Distillation** processes use heat to evaporate water. The gas then condenses, leaving all impurities behind except those (some pesticides and fertilizers) with boiling points lower than water that get evaporated and then condensed along with the water. This method is expensive. It also leaves the water tasteless, and without minerals.
- **Ion exchange** methods work by passing ion-containing water through resin beads, which exchange OH^- and H^+ ions for the unwanted ions.
- **UV** methods use ultraviolet light as a germicide to kill bacteria and other microorganisms in water. These methods do not remove particulates or ions.
- **Chemical-based** methods are used to cause flocculation (the formation of small clumps of particles, making them easier to remove), precipitation or oxidation of particles.

Water Filtration

Filtration is the process of passing a fluid through a porous object or objects (for example cheesecloth or sand) in order to separate out matter in suspension [1]. Filtration is the primary process used to clean water for human use.

Some Vocabulary Clarification

Many words with similar meanings are used to describe parts of the filtration process. These words are used interchangeably in the water filtration literature. These words and their meanings are illustrated in Figure 1.

Kinds of Filtration

The following is a list of commonly used filtration types. All of them use membrane technologies, except for carbon filtration which uses a collection of small grains. Each of these filter types are expanded upon in Table 1, including

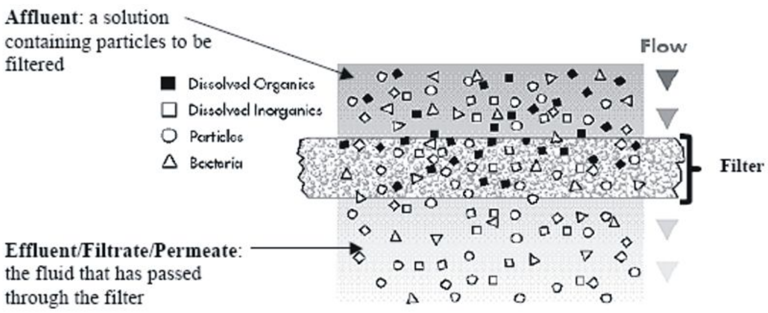


FIGURE 3.60
Particles passing through a carbon filter

2

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examples of particle types they can remove and diagrams of the filters. A simplified version of Table 1 is also provided as a student handout (Types of Filtration Systems and their Traits: Student Handout).

- **Carbon filtration** traps larger organic particles on the surface of small carbon grains. Different types of filters are capable of trapping different substances.
- **Microfiltration** methods employ depth, screen or surface membranes:
  - **Depth filters** consist of matted fibers that retain particles as they pass through the filter. About 98% of the particles passing through this type of microfilter are retained, protecting finer-scale membranes farther down the chain. Depth microfilters are considered good prefilters for this reason.
  - **Surface filters** are multilayered structures that remove 99.99% of suspended solids, and are also used as prefilters.
  - **Screen filters** are microporous membranes that trap particles based on the specific pore size of the membrane.
- **Ultrafiltration** methods employ a thin, yet tough, membrane with a very small pore size.
- **Nanofiltration** methods focus on pore size, charge (repulsion), and shape characteristics of the membrane. A moderate amount of pressure is required for nanofilters to operate effectively.
- **Reverse osmosis** methods use a selectively-permeable membrane to separate water from dissolved substances. Relatively high pressure is required to make water flow against normal osmotic pressure.

Filtration Trade-offs

Generally, the smaller the filter, the more pressure is needed to push the water through it. Greater pressure means a greater cost, and so filters that remove very small particles are the most expensive to use. To be cost-effective, filtration is usually done as a multi-step process. Bigger contaminants are first removed using large-pore (and thus less expensive) filters, then filters with decreasing pore sizes are used to remove smaller and smaller particles. Using a sequence of filters also keeps the small-pore filters from getting clogged up with the large contaminants. This clogging is called “fouling.” Filters must be cleaned regularly to remain usable

State of the Art?

While constantly improving, our current water purification technology is inadequate to meet the current or the projected needs of the world’s population for clean drinking water. New nanofilters are being explored with much anticipation and excitement for their potential to address the global water crisis.

References

(Accessed December 2007.)

- http://www.m-w.com/dictionary/filter
- Adapted from http://www.freedrinkingwater.com/water-education/quality-waterfiltration-method.htm

- Adapted from http://www.homecents.com/images/h2o-imgs/nano_f_l.gif
- Adapted from reverse_osmosis.jpg http://www.zenon.com/image/resources/glossary/reverse_osmosis/ reverse_osmosis.jpg
- http://www.nesc.wvu.edu/ndwc/

TABLE 3.19: Types of Filtration Systems and their Traits

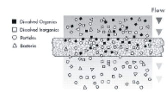
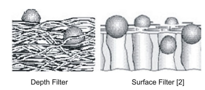
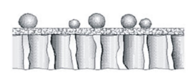
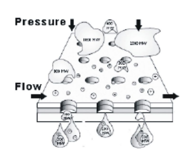
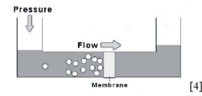
Type of Filtration	Max Particle Size (meters)	Characterization	Example Particles	Disadvantages	Diagram
Carbon Filtration (CF)	Above 10^{-6}	Large organic particles are trapped on the surface of small carbon grains. Used in combination with other filtration processes.	Removes bad tastes and odors (organic matter) and chlorine Varies widely	No effect on total dissolved solids, hardness, or heavy metals.	 [2]
Microfiltration (MF)	10^{-5} to 10^{-7}	Removal based on relatively large pore size, retains contaminants on surface. Very low water pressure needed. Often used as a pre-filter.	Sand, silt, clays, *Giardia lamblia, Cryptospoidium,* cysts, algae and some bacteria	Removes little or no organic matter. Does not remove viruses.	
Ultrafiltration (UF)	10^{-7} to 10^{-8}	Removal based on smaller pore size, retains contaminants on surface. Low water pressure needed.	Suspended organic solids Partial removal of bacteria Most viruses removed	Most problems are with fouling. Cannot remove iron or manganese ions (multivalent ions).	 [2]
Nanofiltration (NF)	10^{-8} to 10^{-10}	Removal based on very small pore size and shape and charge characteristics of membrane. Moderate pressure needed.	Suspended solids Bacteria Viruses Some multivalent ions	Currently most are susceptible to high fouling. Cost is relatively high (currently).	 [3]

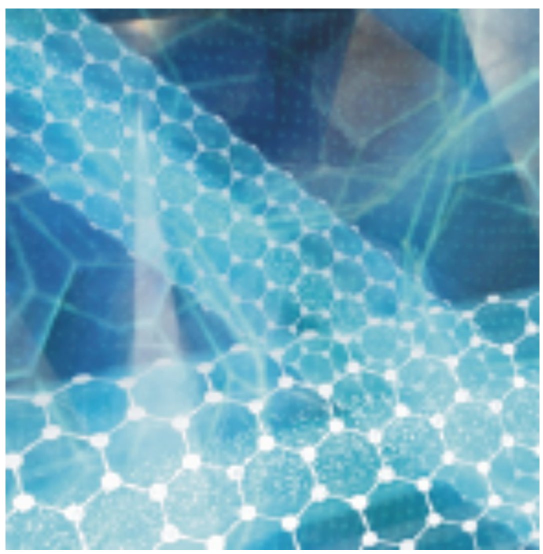
TABLE 3.19: (continued)

Type of Filtration	Max Particle Size (meters)	Characterization	Example Particles	Disadvantages	Diagram
Reverse Osmosis (RO)	10^{-9} to 10^{-11}	High pressure process that pushes water against the concentration gradient Different membranes have different pore sizes and different characteristics.	Suspended solids Bacteria Viruses Most multivalent ions Monovalent ions	Membranes are prone to fouling. Cost is high.	

Note: Relative Pressure needed for operation: $RO > NF > UF > MF$

Relative Cost: $RO > NF > UF > MF$ [5]

Nanofiltration



Environmental scientists and engineers are creating nanomembranes to filter contaminants from water cheaply and effectively

Water Filtration Methods

There are simple and cheap ways to filter contaminants out of water

Sand, Gravel, and Charcoal Filtration

- Pouring water through sand, gravel, or charcoal are simple and inexpensive methods of cleaning water

Small Contaminants Pass Through

- Sand, gravel, and charcoal don't filter out some contaminants, like
  - bacteria

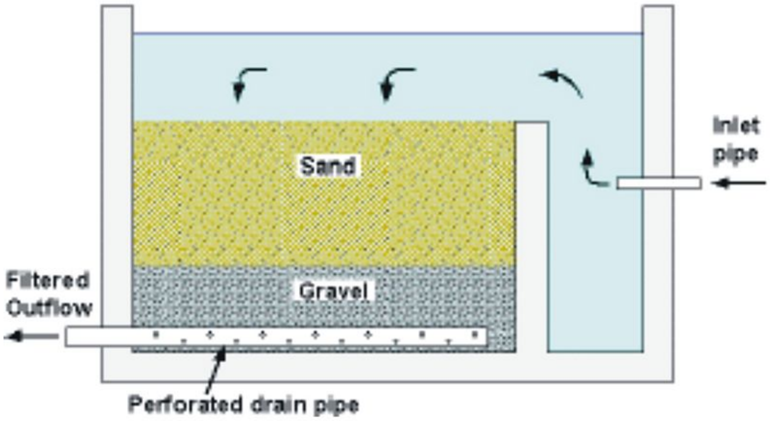


FIGURE 3.61

Sand and gravel filtration

- viruses
- industrial pollutants
- agricultural pollutants
- salt

Question

How Can We Trap Smaller Contaminants?

Membrane Filter Technology I

- A membrane is a thin material that has pores (holes) of a specific size
- Membranes trap larger particles that won't fit through the pores of the membrane, letting water and other smaller substances through to the other side

Membrane Filter Technology II

- There are four general categories of membrane filtration systems
  - Microfiltration
  - Ultrafiltration
  - Nanofiltration
  - Reverse Osmosis

TABLE 3.20: **Membrane Filter Technology III**

Filter type	Symbol	Pore Size, μm	Operating Pressure, psi	Types of Materials Removed
Microfilter	MF	$1.0 - 0.01$	< 30	Clay, bacteria, large viruses, suspended solids
Ultrafilter	UF	$0.01 - 0.001$	$20 - 100$	Viruses, proteins, starches, colloids, silica, organics, dye, fat

TABLE 3.20: (continued)

Filter type	Symbol	Pore Size, μm	Operating Pressure, psi	Types of Materials Removed
Nanofilter	NF	0.001 – 0.0001	50 – 300	Sugar, pesticides, herbicides, divalent anions
Reverse Osmosis	RO	< 0.0001	225 – 1,000	Monovalent salts

(*Source:* http://web.evs.anl.gov/pwmis/techdesc/membrane/index.cfm)

Microfiltration

- Typical pore size: 0.1 microns (10^{-7} m)
- Very low pressure
- Removes bacteria, some large viruses
- Does not filter
  - small viruses, protein molecules, sugar, and salts

Ultrafiltration

- Typical pore size: 0.01 microns (10^{-8} m)
- Moderately low pressure
- Removes viruses, protein, and other organic molecules
- Does not filter inoic particles like
  - lead, iron, chloride ions; nitrates, nitrites; other charged particles

Nanofiltration

- Typical pore size: 0.001 micron (10^{-9} m)
- Moderate pressure
- Removes toxic or unwanted bivalent ions (ions with 2 or more charges), such as
  - Lead
  - Iron
  - Nickel
  - Mercury (II)

Reverse Osmosis (RO)

- Typical pore size: 0.0001 micron (10^{-10} m)
- Very high pressure
- Only economically feasible large scale method to remove salt from water
  - Salty water cannot support life
  - People can't drink it and plants can't use it to grow

How RO Works

- Osmosis is a natural process that moves water across a semipermeable membrane, from an area of *greater concentration to* until the concentrations are equal
- To move water from a *more concentrated area to a less concentrated area* requires high pressure to push the water in the opposite direction that it flows naturally

FIGURE 3.62

FIGURE 3.63

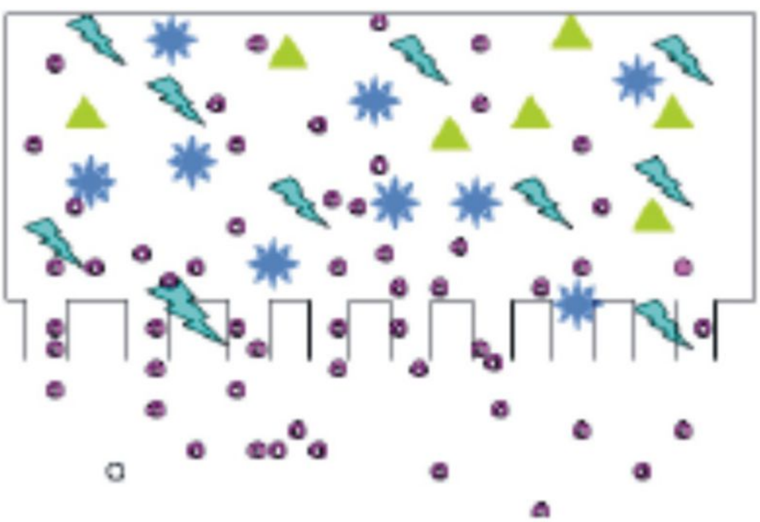


FIGURE 3.64

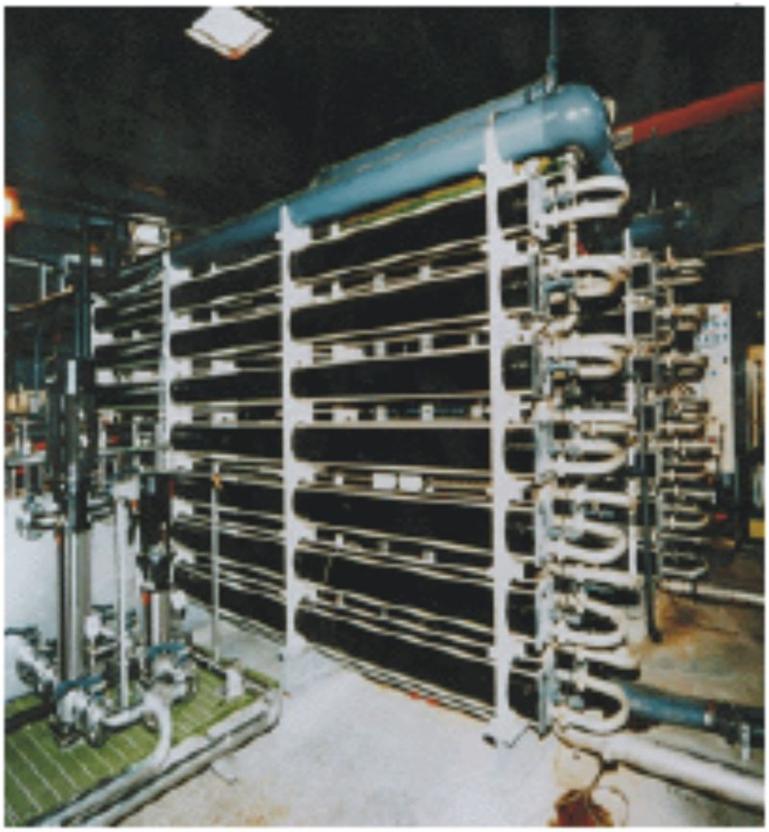
Microfiltration water plant, Petrolia, PA

A microfilter membrane

FIGURE 3.65

An ultrafiltration plant in Jachenhausen, Germany

FIGURE 3.66



Nanofiltration water cleaning serving Mery-sur-Oise, a suburb of Paris, France

FIGURE 3.67


Reverse osmosis (or desalination)
water treatment plants, like this one,
are often located close to the ocean

FIGURE 3.68

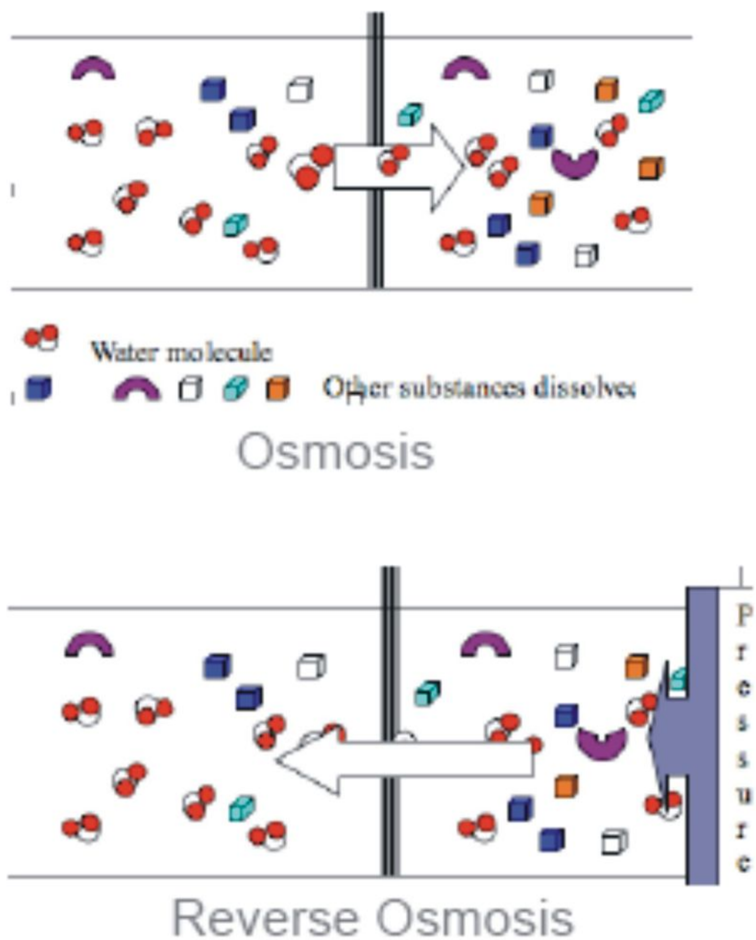

Water molecule
Other substances dissolved
Osmosis
Pressure
Reverse Osmosis

FIGURE 3.69

Question

If RO Can Get Everything Out That Would Make Water Undrinkable, Why Not Just Use RO Membranes by Themselves?

RO is Not for Everything!

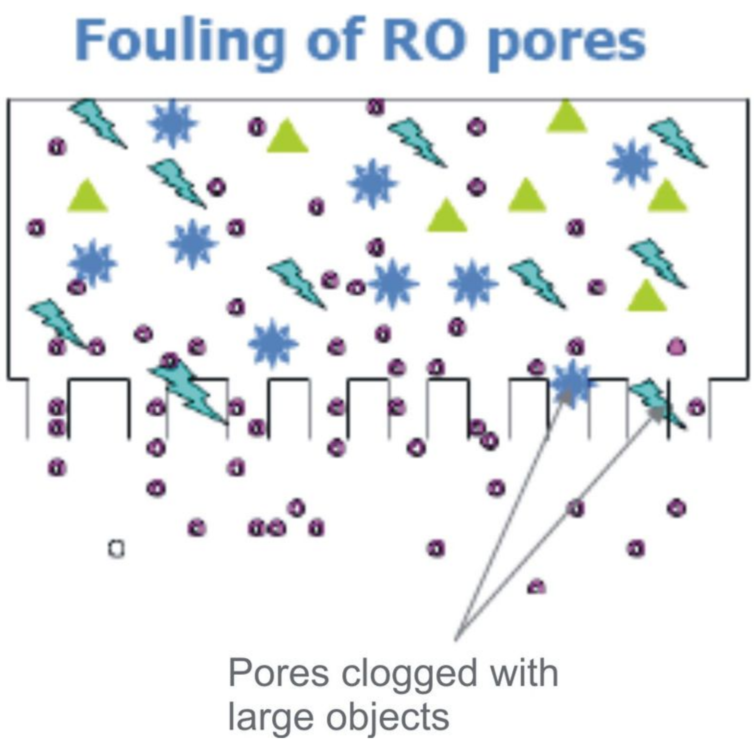


FIGURE 3.70

- High pressure is required to push the water through the smallest pores
  - RO is the most $$$ filtration system
- Because pores are so small, big particles can clog them (called fouling)
  - This makes the filtering membrane unusable

Question

How Can We Keep Large Particles from Fouling Membranes with Small Holes?

A Series of Filtrations Increases Efficiency

- Filters can be sequenced from large to small pore size to decrease fouling
  - They must still be cleaned regularly to remain usable

Water Filtration Chart

Nanofiltration vs. Reverse Osmosis

- Using RO to get rid of very small particles is very expensive
  - Could we do it more cheaply?

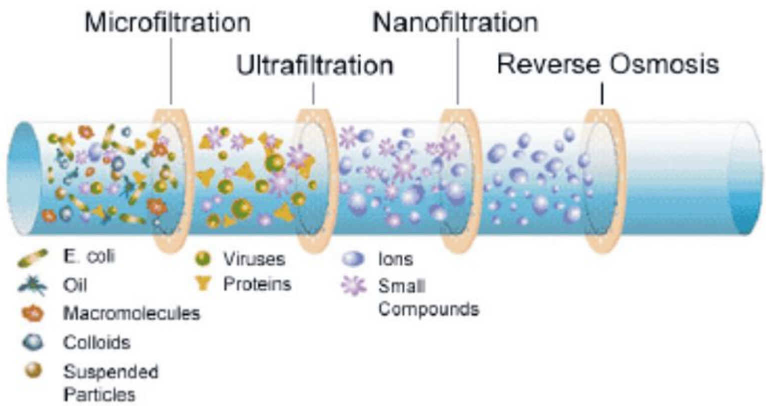


FIGURE 3.71

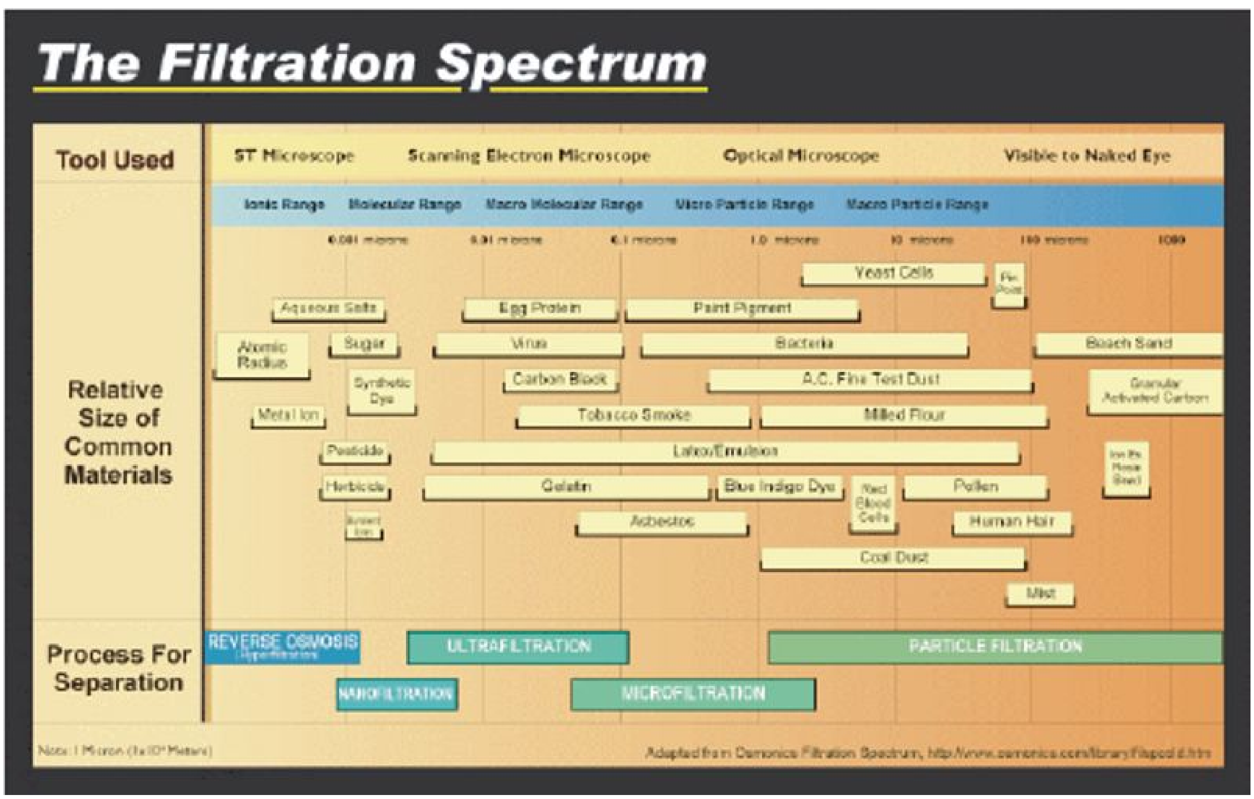


FIGURE 3.72

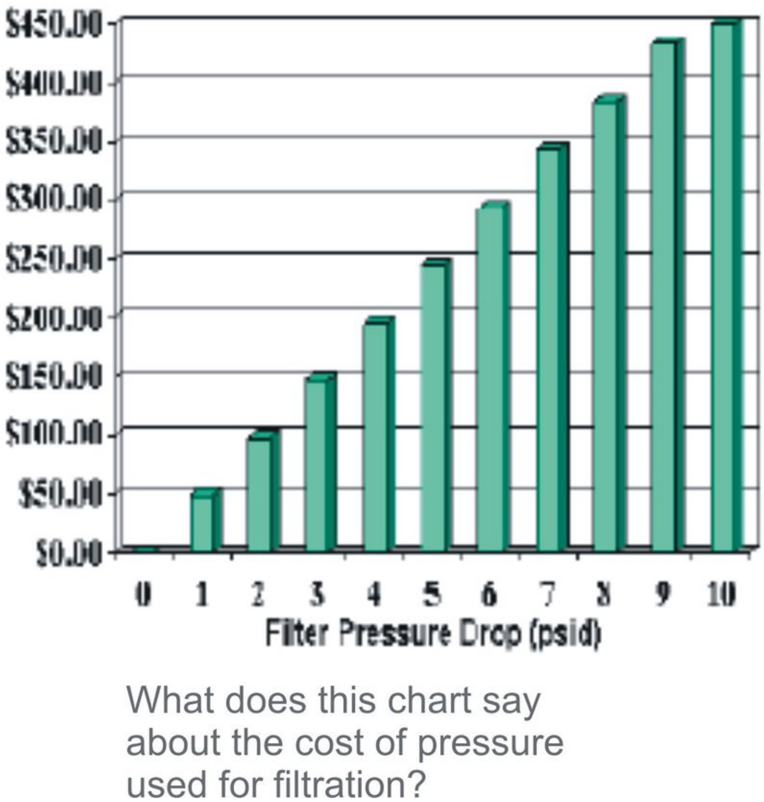


FIGURE 3.73

- Nanofiltration requires much less pressure than reverse osmosis
  - Less pressure means lower operating costs!

Advantages of Nanofiltration

- Nanofilters are close in size to RO filters, but cost much less to run
- And special properties of nanosized particles can be exploited!
  - We can design new nanofilters that catch particles smaller than they would catch based on size alone
- Scientists are exploring a variety of methods to build new nanomembranes with unique properties to filter in new and different ways

New Nanofilters are Unique!

- Nanomembranes can be uniquely designed in layers with a particular chemistry and specific purpose
  - Insert particles toxic to bacteria
  - Embed tubes that "pull" water through and keep everything else out
  - Signal to self-clean

New Nanomembranes I

- Imagine having layers of membranes into which specialized substances are placed to do specific jobs
  - You can put a chemical in the filter that will kill bacteria upon contact!

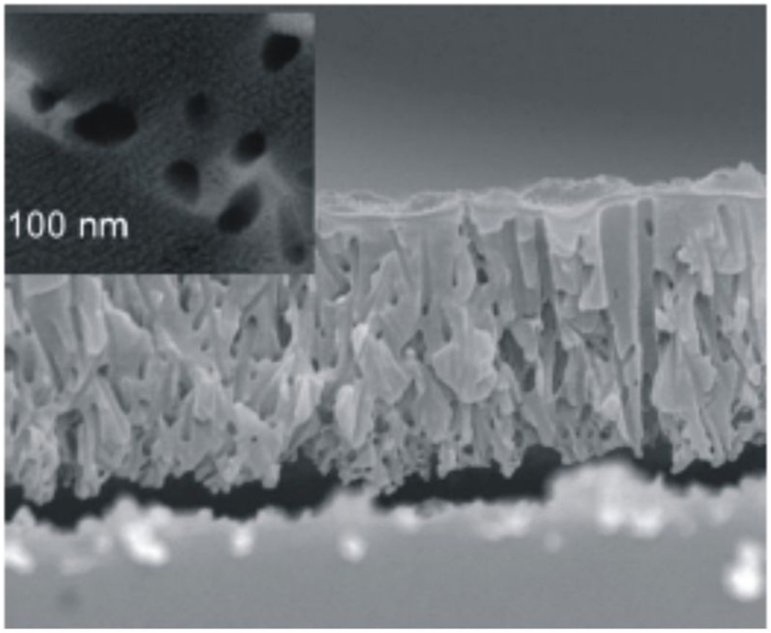


Image of a nanomembrane

FIGURE 3.74

Chemicals toxic to bacteria could be implanted in nanomembranes

FIGURE 3.75

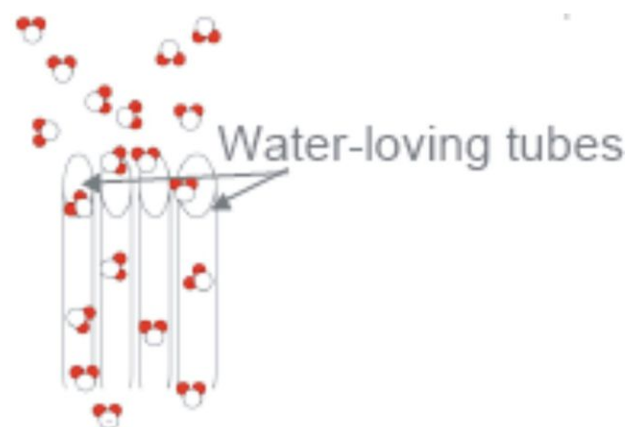
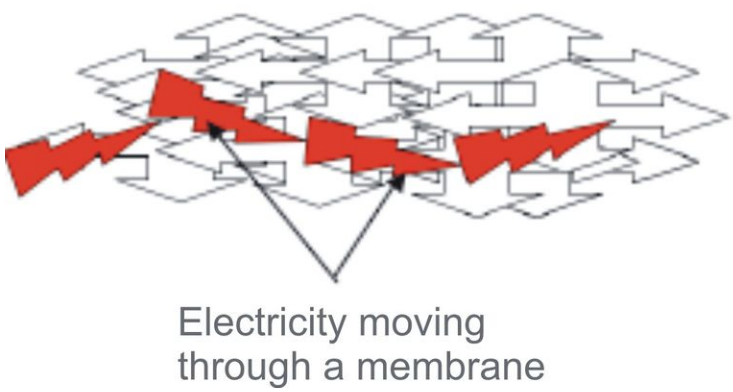


FIGURE 3.76



New Nanomembranes II

- Embed “tubes” composed of a type of chemical that strongly attracts (“loves”) water
- Weave into the membrane a type of molecule that can conduct electricity and repel oppositely charged particles, but let water through

1 nm **Sized Nanopores Repel Electronegative Objects**

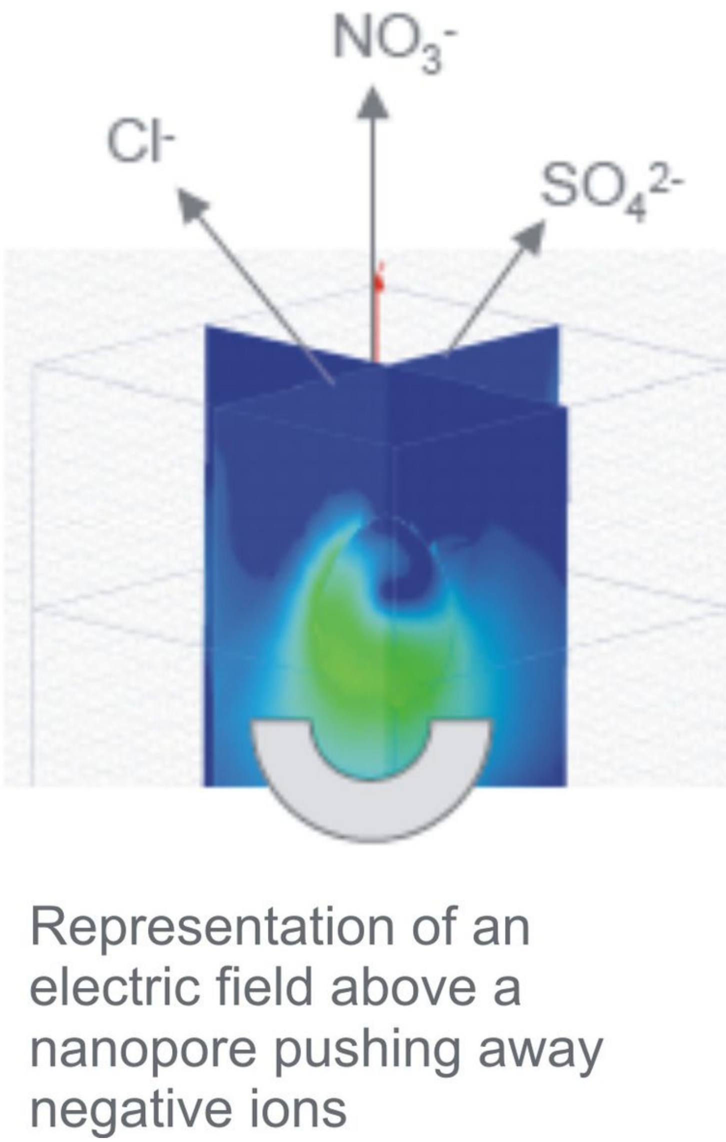


FIGURE 3.77

- 1 – 2 nm sized pores create an electric field over the opening
  - This electric field is negative, and repels negatively charged particles dissolved in water
  - Most pollutants from agriculture, industry, and rivers are negatively charged
- But water can get through!

Nanofiltration Summary

- At the nanoscale, filters can be constructed to have properties designed to serve a particular purpose
- Scientists and engineers are now experimenting to create membranes that are low-cost yet very effective for filtering water to make it drinkable!
- These inventions may help to solve the global water shortage

Questions

- How do you determine what filtration method to use to remove contaminants in a water sample?
  - Consider the size of the contaminants, the relative cost of the filtration methods, and the water use
- What are two benefits that nanomembranes bring to the filtration of water?
  - Consider how they can help to address the world's problem of a scarcity of clean drinking water
- Describe three ways that current or experimental nanofiltration membranes may be different than previous generation membranes

Teacher Notes

Overview

This set of slides provides some general background about the processes of water filtration. Common processes involve a sequence of filtrations through different kinds of membranes designed to remove different sizes of particles. Water is also often treated chemically, is sometimes irradiated, and even has substances added back into the water to improve its flavor. These slides give students a broad background in water filtration so that they can appreciate the innovations being explored by scientists and engineers who are designing nanomembranes for water filtration.

Slide 1: Title Slide

Slide 2: Water Filtration Methods

Removing contaminants to make water drinkable can be complex. Although the focus of this lesson is on membrane filtering technologies, there are simple and cheap methods for removing large contaminants in water, such as passing water through gravel, sand, and/or charcoal.

Slide 3: Sand, Gravel, and Charcoal Filtration

Students will be working with sand, gravel, and charcoal filtration in their lab activities. These are the very simple, inexpensive methods for cleaning large-sized contaminants out of water.

Slide 4: Small Contaminants Pass Through

However, sand, gravel, and charcoal filtration methods are not able to remove bacteria, viruses, and industrial or agricultural pollutants from water. If a water source has any of these contaminants, other filtration or cleaning methods must be used as well to produce safe drinking water.

Slide 5: How Can We Trap Smaller Contaminants? (Question Slide)

Have your students brainstorm ideas about ways to trap small contaminants like bacteria or viruses, which are not trapped by sand, gravel, or charcoal filtration.

Slide 6: Membrane Filter Technology I

This slide introduces students to the idea of a membrane blocking some (e.g., smaller) substances while allowing others to pass through. The basis of most membrane blockage is pore size. The size of the pore will determine what substances pass through the membrane and which ones remain on the other side.

Slide 7: Membrane Filter Technology II

This slide lists the four common types of membranes used for filtering water for drinking. There are many types of filters and methods of cleaning water, but this slide set focuses primarily on membrane technology, leading into a discussion of nanomembranes.

Slide 8: Membrane Filter Technology III

This is a quick overview that compares the four types of membrane filters on the basis of pore size, operating pressure, and type of substances that each of the membranes can remove. Students will look at these in more detail during the Cleaning Jarny's Water activity.

Slide 9: Microfiltration

The pore diameter of microfiltration membranes is typically in the range of 0.01 to 1.0 micrometers , with a typical diameter of 0.1 microns . Thus, microfiltration can be used to filter bacteria and some large viruses from water. It cannot filter out smaller contaminants like small viruses, proteins, molecules, sugar, and salts. The pressure required to push water through a microfiltration membrane is minimal. This slide shows a picture of a microfiltration water treatment plant and a close-up of a microfiltration membrane. You can see the pores in this membrane!

Slide 10: Ultrafiltration

Ultrafiltration can remove viruses, proteins, and other organic molecules from water using a moderately low amount of pressure. Ultrafiltration is an economical choice since not very much pressure is required to operate an ultrafiltration water treatment plant.

This slide would be a good place to point out that ions are charged particles that get dissolved into the water from natural and unnatural sources. Water, as a universal solvent, has the potential to dissolve small amounts of whatever the water passes over. Nitrates and/or nitrites and phosphates in excess in the water can be a sign of agricultural pollutant run-off.

Increased nitrates and/or phosphates in the water can lead to a series of events that ultimately cause a lake to lack sufficient nutrients to support fish life. At first, increased nitrates and phosphates provide basic nourishment to plants that will stimulate plant growth. Plant growth leads to an abundance of food for animals. Animal populations tend to increase as well when plant growth is surging. But too many animals in the water decreases the amount of dissolved oxygen, which is necessary for fish to live. Dead fish in the water decompose, providing nutrients for even more algae to grow. These events can lead to what is known as eutrophication, or a series of cause and effect events that lead to changing the ecosystem of a lake resulting in troubling impacts: decreased biodiversity and changes in the dominant species. This concept is not addressed at all within this lesson, but if appropriate, you may want to mention it.

Slide 11: Nanofiltration

This slide introduces "traditional" nanofiltration, which, like many of the other filtration technologies, has been around for decades. Later slides will talk about some of the new an innovative work occurring in the science and engineering of nanofilters.

Nanofiltration can remove bivalent ions (ions with more than one charge). Several nanofiltration plants have been built worldwide, but they are still relatively uncommon. This membrane technology is typically used when there is a limited amount of salt in the water.

Slide 12: Reverse Osmosis (RO)

Reverse osmosis (RO) is a membrane technology, about 35 years old, that can separate salt from water. RO membranes have essentially remained unchanged in recent decades. Though RO is the only known technology currently capable of desalinizing water, the process requires very high pressure, and is the most expensive membrane filtering system. Cities located by oceans are often good candidates for cleaning salt out of water.

Slide 13: How RO Works

As highlighted in the previous slide, reverse osmosis is the most successful and effective method of removing salt from water. These illustrations show how osmosis, a natural cellular process, pushes water across cell membranes by going in a direction that is more concentrated (and will therefore, be diluted when more water is added), until the concentrations are equal on both sides of the membrane. In our bodies, our kidneys perform this function.

Dialysis tubing is a common piece of lab equipment used in high school biology labs to demonstrate osmosis. Reverse osmosis goes in the "unnatural" direction, from the side that is more concentrated (without as many substances dissolved in the water) through the membrane to the side that is less concentrated. A great deal of pressure must be applied to push the water into an area less concentrated. The greater the pressure required to move the water through the filtration membrane, the higher it costs to operate the filtering system.

Slide 14: If RO Can Get Everything Out That Would Make Water Undrinkable, Why Not Just Use RO Membranes by Themselves? (Question Slide)

Have your students brainstorm about why RO by itself might not be the best solution. Ideas that they may entertain include: high cost (since RO requires high pressure), plugging of the RO membrane from large particles, and that not all water has salt in it that needs to be removed (e.g., fresh or lake water) so RO may be overkill in some cases.

Slide 15: RO is Not for Everything!

This slide points out that high pressure, high cost, and fouling are associated with using RO membranes. More pressure requires more energy use. Designing and maintaining (cleaning) a very small pore size is also very costly. You might point out that in the image, a few of the particles are blocking some of the pores.

Slide 16: How Can We Keep Large Particles from Fouling Membranes with Small Holes? (Question Slide)

Read the question posed on the slide out loud, and have your students brainstorm answers. Fouling can occur with every membrane filter system, when the pores of the filter become plugged with particulate matter that is larger than the pores.

The next two slides address this question, showing how filtering technology can occur in a step-wise fashion to optimize the more expensive filtration systems.

Slide 17: A Series of Filtrations Increases Efficiency

This slide illustrates the consecutive removal of increasingly small contaminants using a series of filters. It is less expensive to remove larger-sized contaminants with gravel, sand, or charcoal, and to use a series of increasingly smaller pore-sized membranes to remove increasingly smaller particles than to remove all sizes of particles with the membranes with the smallest sized pores. The filters would quickly foul and be in frequent need of cleaning. Using nanofiltration or RO to remove only small particles optimizes these expensive membranes for those sized particles that can only be filtered out of water by them.

Slide 18: Water Filtration Chart

This is a picture of the Filtration Spectrum: Student Handout that correlates the types of particles with their size, type of filter required to remove the particle from the water, and the type of microscope needed to view these sizes of particles. It illustrates the filtration methods that have been discussed so far. You might use the chart to quickly review the various methods that have been discussed.

Slide 19: Nanofiltration vs. Reverse Osmosis

This slide points out that RO can get rid of small particles, but it is expensive. Can we remove small particles more cheaply?

This graph demonstrates the correlation between the amount of pressure required and the cost of the water filtration system. The more pressure, the more energy is required, and the higher the operating cost.

Slide 20: Advantages of Nanofiltration

The pores in nanomembranes are close in size to those in RO filters, so can they be used more often as a cheaper alternative to RO? Yes, mainly due to recent advances in nanotechnology.

Nanomembranes have been around for decades, and were usually composed of a homogenous material throughout the fabric of the membrane. Recently, however, scientists have been able to build nanomembranes in layers, inserting substances with a particular chemistry and specific purpose. For example, new nanomembranes can not only filter based on *size* but also based on *charge.* In other words, the membrane can stop very small particles with a particular electrostatic charge while allowing water through.

Such advances have been made possible because of new tools and methods. Emphasize that engineering membranes to be uniquely designed for a specific purpose is a characteristic of nanofiltration and nanotechnology in general.

Slide 21: New Nanofilters are Unique!

Scientists can embed noxious substances in nanomembranes—substances that will kill bacteria on contact! Also, channels can be built into the membranes that are surprisingly hydrophilic, *attracting* water to pass through the membrane, thus reducing the pressure needed to *push* the water through it. Further, scientists envision creating membranes that are self-cleaning: a feedback mechanism initiates a chemical process that removes fouling residue. Using self-cleaning membranes could reduce both maintenance and operating expenses.

Benefits of nanomembranes are elaborated in more detail in the New Nanomembranes: Student Reading.

Slide 22: New Nanomembranes I

Eric Hoek talks about embedding particles into the membrane that are toxic to bacteria in the New Nanomembranes: Student Reading. When the bacteria combine with the toxic embedded substance, the bacteria die.

Slide 23: New Nanomembranes II

Two advances of new nanomembranes include the embedding of hydrophilic tubes through which water travels to the other side of the membrane, and the weaving of a conducting material through a membrane to repel oppositely charged particles.

Slide 24: 1 nm Sized Nanopores Repel Electronegative Objects

Eric Hoek explains this idea in the New Nanomembranes: Student Reading. This discovery was made serendipitously when constructing membranes with 1 to 2 nanometer pores.

Slide 25: Nanofiltration Summary

This slide concludes the introduction of how nanomembranes can be used to filter contaminants out of water. Hopefully students have gained an appreciation for how nanomembranes can be built with selected properties by embedding them with specialized materials. Nanomembranes hold the promise of a new generation of water filtration membrane technology.

Slide 26: Questions for Discussion

This final slide poses further questions for discussion that are related to this lesson. You may want to ask students to discuss their ideas aloud or in writing, to reinforce the central concepts.

Which Method is Best? Teacher Instructions #38; Answer Key

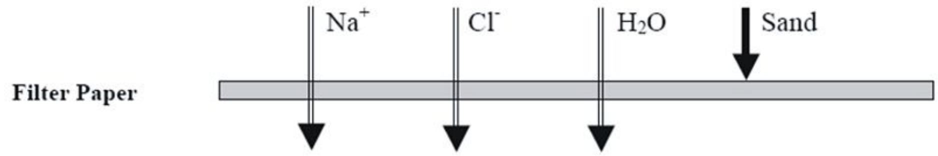
Purpose

Use the Filtration Spectrum: Student Handout to determine which filtration method is best suited to filter a variety of particles.

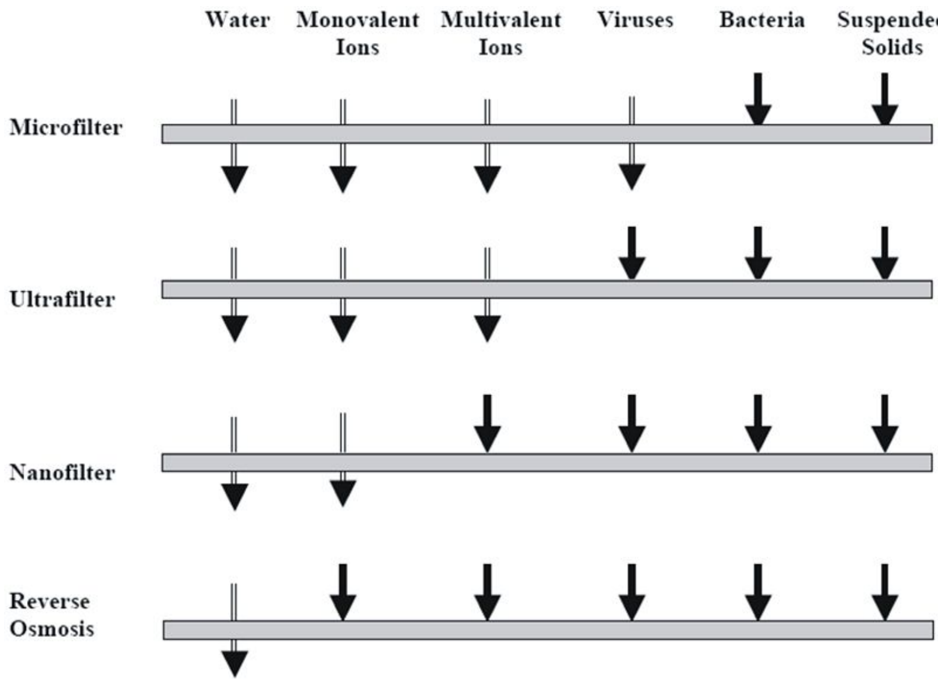
The goal is to have students actively use the information in the handout to become familiar with the limitations of each filtration method. This exercise will also help students visualize the transport of particles, and not others, through different membranes.

Introduction and Example

If you had a filter that was made of paper, it would not let sand pass through but would allow water and dissolved sodium chloride pass through. To demonstrate this, you would draw the following arrows:



Refer to the Filtration Spectrum handout. Based on what you see in the handout, draw arrows that show which particles will pass through each membrane and which will not.



Comparing Nanofilters to Conventional Filters Lab Activity: Teacher Instructions

This lab activity demonstrates the concept of filtration as a means of separating a variety of substances from water using a variety of filtration techniques (Part I), and then compares ultrafiltration with nanofiltration (Part II). In particular, students will observe and test "river water" to identify the substances mixed and dissolved into the water, and then run the water through a series of filtration systems, ending with nanofiltration. They will perform chemical tests and make visual observations to determine if the substances originally identified in the water remain in solution after using various filtration techniques, and report their results on lab sheets.

If you have already conducted this type of investigation using filtration, you may go directly to Part II, comparing ultrafiltration with nanofiltration. Rather than creating the "river water" and testing it according to the directions specified below, you may simply want to purchase a water-testing kit and collect your own sample of river water (pond water, lake water, etc.).

The company Argonide manufactures and sells a nanofiltration kit that contains everything that you need for the nanofiltration activities in this lab. To purchase, contact:

Henry Frank, Sales and Marketing Manager

Argonide Corporation (www.argonide.com)

291 Power Court, Sanford, FL 32771-1943

Email: henry@argonide.com, Tel: 407-322-2500, Fax: 407-322-1144

with this order information:

Product #: MTK-SRI

Description: NanoCeram Media Test Kit (complete)

Price: 1-10 kits: $216.50/kit; 11-49 kits: $201.84/kit; 50+ kits: $187.19/kit.

Overview

You are on a backpacking trip in the mountains with a friend. Each of you has brought 2 liters of water with you and you are running very low. You had planned to stay at least for another day, but realize that if you don't find a source of clean drinking water, you will need to turn back and end your trip early. You brought with you some water testing strips and a nanofilter that fits inside of a syringe, just in case you needed to drink the water from the river. Your job is to use your testing strips to find out what else, besides what you can see (such as leaves) is in the water. Once you find what is in the water, you will have to filter out any of the unwanted substances.

The pores of your nanofilter are so small that they will easily plug with large substances.You want to filter as much as you can using the gravel and the sand by the river in a funnel. You have also brought activated charcoal with you.

Can you make the river water clean enough to drink, or do you have to turn around and go home?

Materials for Each Station: Filtration (Part I)

- 1/2 cup sand
- 1/2 cup gravel
- About 50 mL of activated charcoal
- 1 25 mm NanoCeram® nanofilter disc
- 1 Luer-Loc filter housing (to hold the nanofilter)
- 2 250 mL beakers
- 1 funnel
- Paper towels
- Syringe
- Test strips for nitrate and nitrite ions
- Test strips for chloride ions
- Test strips for copper
- Test strips or drops for iron(II) and iron(III) ions
- 1/2 liter of "river water" in a bottle

Materials to Make 1.0 Liter **of "River Water" for Two Lab Stations**

- 2 half-liter bottles
- 1 liter of distilled water
- 1/2 teaspoon salt
- A few crushed leaves
- 3 pinches of dirt
- 2 pinches of sand
- 2 teaspoons table salt
- 2.5 mL *No More Algae* liquid by Jungle, 0.05% (by volume) copper sulfate pentahydrate (source of copper liquid)
- 1 crushed tablet of Fe(27 mg) purchased at a drug or grocery store

Materials for Each Station: Comparing Ultrafiltration with Nanofiltration (Part II)

- 1 25 mm NanoCeram® nanofilter disc
- 1 25 mm Millipore VS ultrafilter disc
- 1 Luer-Loc filter housing (to hold the nanofilter and the ultrafilter)

- Syringe
- Bottle of water containing dissolved dye
- (2) small effluent collectors
- Paper towels

Procedures: Filtration (Part I)

Mix together all of the river water ingredients and pour into two half-liter bottles.

Distribute river water and materials to each lab station, and post the student instructions at each lab station for students to follow.

Each student should have their own lab sheet for recording their data and answering questions.

Setup

1. Put the charcoal in water to soak for at least 10 minutes , and proceed with the next step. After 10 minutes , take the charcoal out and rinse it thoroughly to prevent coloring the water.
2. Arrange the ring on the ring stand and put the empty funnel inside of the ring, as shown in Figure 1. Put the 250 ml beaker underneath the funnel so it will catch the effluent.
3. Look at the river water in the bottle. Record your observations of the river water on your lab sheet. Be sure to notice texture, colors, and anything else that stands out.
4. Follow the instructions in the Ion Testing box below to test the river water for the presence of the ions.

Ion Testing

1. Label a paper towel with each of the symbols of the ions you will test:

Fe^{2+} Fe^{3+} Cl^{-} $NO_3{}^{-}$ $NO_2{}^{-}$ Cu^{2+}

2. Dip the appropriate strips in the river water to test for these ions.

3. Put the wet strips on a paper towel under their appropriate symbols so you don't forget which strip represents a test for which ion.

4. Match the color of your strip with the color chart on the side of the relevant test strip bottle. The amount of the ion in your river water sample will be listed underneath the matching color square on the bottle.

5. Record on your lab sheet the color of the strip and the amount of each ion indicated by the test strip.

You will repeat this "ion testing" step after each filtration to find out if the ions are still present in the water.

Table 1 summarizes the consequences of the presence of these ions in drinking water.

TABLE 3.21: Ions and Consequences in Drinking Water

Ions	Consequences in Drinking Water
Fe^{2+} and Fe^{3+}	These ions indicate that rust from pipes has gotten into the water. While rust is not dangerous, it makes the water taste bad and leaves mineral deposits in sinks and bathtubs.
$NO_3{}^{-}$ and $NO_2{}^{-}$	These ions are an indication that pesticides from agriculture have gotten into the water.
Cl^{-}	This ion indicates that salt has intruded into the water. People cannot use salty water for drinking. Salty water usually cannot be used for agriculture either, although there are a few exceptions.

TABLE 3.21: (continued)

Ions	Consequences in Drinking Water
Cu^{2+}	Copper is normally found in water from natural sources as well as from corrosion of the copper pipes used for water. Copper is not harmful in quantities less than $1000-\mu m$.

Gravel Filtration

1. Put 1/2 cup of **gravel** into the funnel.

2. Put a clean 250 mL beaker underneath the funnel.

3. Pour the river water supplied by your teacher over the gravel. Notice if the gravel stopped any of the substances that you saw in the water from going into the beaker below.

4. Record your observations on your lab sheets.

Gravel and Sand Filtration

5. Put 1/2 cup of **sand** on top of the gravel in the funnel.

6. Put a clean 250 mL beaker under the funnel.

7. Pour the contents of the first beaker, the effluent, into the funnel on top of the sand. Notice if the sand and gravel stop any of the substances in the water from going into the beaker below.

8. Record your observations on your lab sheet.

9. Rinse the empty 250 mL beaker and place it underneath the funnel.

Gravel, Sand, and Activated Charcoal Filtration

10. Put the **activated charcoal** into the funnel on top of the sand and the gravel.

11. Pour the remaining water (the effluent) left from the sand filtration step into the funnel on top of the charcoal. Notice if the charcoal removes anything else.

12. Record your observations on your lab sheet.

Conduct Ion Test

13. Using the test strips, test for the presence of the ions in the filtered water by following the instructions in the Ion Testing box above.

14. Record the results of your ion tests on your lab sheet and answer the questions.

Nanofiltration

15. Get a 25 mm NanoCeram® nanofilter disc and a Luer-Loc ceramic filter housing.

16. Open the filter housing and carefully place the disc into the filter housing, place the O-ring on top of the disc, and close securely, making sure the disc is centered in the housing to prevent leakage around the edges of the disc.

17. Rinse the empty 250 mL beaker and place it underneath the filter.

18. Fill the syringe with the effluent collected after filtering with the charcoal, sand, and gravel.

19. Screw the filter housing onto the syringe, taking care not to depress the plunger of the syringe during this operation.

20. Push the effluent through the nanofilter using even, steady pressure.

21. Record your observations of the solution after it has gone through the nanofilter on your lab sheet.

Conduct Ion Test

FIGURE 3.78

Funnel supported by ring with beaker underneath to catch effluent

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22. Using the test strips, test for the presence of the ions in the filtered water by following the instructions in the Ion Testing box above.

23. Record the results of your ion tests on your lab sheet and answer the questions.

Procedures: Comparing Ultrafiltration with Nanofiltration (Part II)

You have just used a new nanofilter (the NanoCeram filter) that has recently come to market. An older ultrafilter, called the Millipore VS filter is also available. The NanoCeram® filter is a multilevel woven membrane with various nanoparticles embedded into the layers of membranes. The Millipore VS membrane is a nonwoven, matte-like paper.

The purpose of this part of the lab activity is to compare the anofilter with the ultrafilter based upon the following two criteria:

- Completeness of filtration
- The relative amount of pressure needed to push the water through each filter

The completeness of filtration will be measured by filtering dissolved dye through each of the filters and looking at the color of the filter and the effluent. The relative pressure needed for filtration will be measured by how hard you have to push the syringe to get the water to pass through the filters.

Compare Millipore VS and NanoCeram® Filtration

1. Open the bottle containing the dissolved dye and draw 2 – 3 mL into the syringe.
2. Open the Luer-Loc filter housing and carefully place a single 25 mm disc of **Millipore VS** membrane material into it. Place the O-ring on top of the disc and close securely, making sure the disc is centered in the housing to prevent leakage around the edges of the disc.
3. Screw the filter housing onto the syringe, taking care not to depress the plunger of the syringe during this operation.
4. Depress plunger of the syringe while holding the syringe over an effluent collector to capture the fluid as it exits the syringe through the filter housing.
5. Apply enough pressure to ensure that the dissolved dye is passing through the filter media. *Typical results for this stage using the Millipore VS membrane material show only several drops coming out of the syringe due to the extreme amount of pressure required to force the dissolved dye through the filter.*
6. Once this is completed, carefully remove and open the filter housing, and remove the filter membrane.
7. Place the membrane aside, next to the effluent collector containing the effluent from this test.
8. Rinse the syringe and repeat the sequence of steps 1-7 above, but with the **NanoCeram®** filter. Push the dissolved dye through gently and steadily; avoid pushing fast.
9. Compare the color of the effluent from the two filters, the color of the filters, and how easy or hard it was to push the dissolved dye through the filters with the syringe.
10. Record your observations on your lab sheet.
11. Answer the questions on your lab sheet.
12. Clean your lab station.

References

(Accessed January 2008.)

- http://icn2.umeche.maine.edu/newnav/newnavigator/images/P7280072.JPG

Cleaning Jarny's Water: Teacher Instructions #38; Answer Key

This problem-solving activity is based on a real world story about the water of Jarny, France. A problem scenario is presented in which students use data to compare Jarny water quality (i.e. levels of substances) with Environmental

Protection Agency fresh drinking water standards. Students will determine which substances need to be filtered from the water to make it safe to drink. Students are asked to design one or more additional water filters to make the water safe to drink for the people of Jarny.

Students may use The Filtration Spectrum: Student Handout, which shows particle size, particle type, and appropriate filtration system as a resource to guide their work. It is recommended that the students work in heterogeneous ability groups of three or four and that they share with the class the water filtration systems that they have designed.

There's a Problem with Our Water...

In the Eastern part of France, in the city of Jarny (see Figure 1), the local people have a serious problem with their drinking water. Their main source of drinking water comes from the ground water table located near an old iron mine. (See Figure 2 for an explanation of ground water.)

The water has always been pumped out of the mine and filtered before being used for drinking water. When the mine was active, this system worked fine. But since closing, the water has flooded up into the mine, creating a pool of standing water that seeps into the ground water used for drinking.

FIGURE 3.79
Jarny France *green arrow*

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Over time, the water sitting in the mine reacted with the debris left in the abandoned mine, leaving much of the water contaminated. A local water-monitoring agency has watched the rising contamination levels and determined that the current water cleaning system is not good enough to make the water safe to drink. Even before the water flooded up into the mine, a few substances were slightly above safety limits, but now their levels are even higher.

Water that comes from rain (precipitation) trickles through the ground (infiltration) until it flows to an area that it can't pass through, such as bedrock. Fresh water accumulates in these places and is referred to as *ground water*. The top of the ground water is the water table. When this underground water is large enough, it is called an aquifer. Aquifers are a commonly used source of fresh drinking water for people all over the world.

Now that you have some background on the water problem facing Jarny, your team's job is to design a system to clean the water to make it drinkable by the local residents. To do this you will need to do the following:

1. Analyze the data in Table 1 to identify what harmful substances are present in the water. This table provides

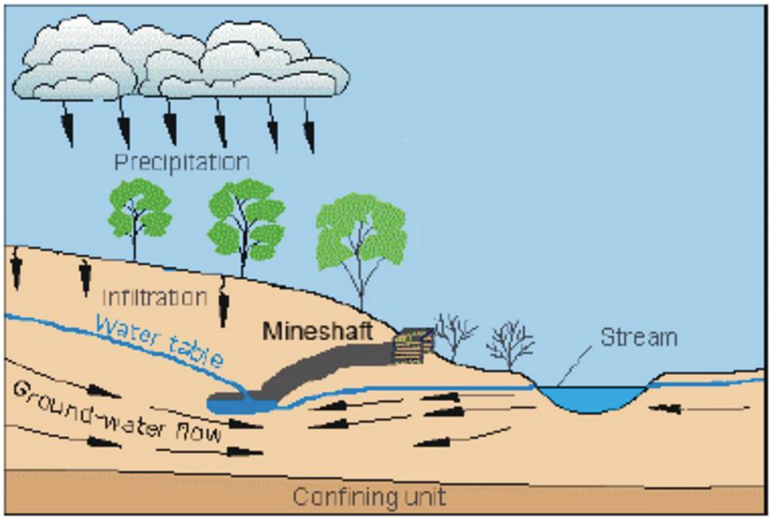

FIGURE 3.80
Ground water
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raw water measurements on a set of substances, selected due to their change in concentration before and after the flooding.

2. Complete question 1 in the Student Report. Record the following information for each substance:

- The name of the substance identified to be filtered out of the water
- The amount the substance is over the acceptable limit
- The ranking of substances by size (1 = largest)
- The least expensive filter needed to filter the substance identified

3. Analyze the data on the current water cleaning system (Table 2), your reading handouts, and relevant charts to help inform your design of a system to clean the water to make it drinkable. Assume that your design will be added on to the system currently in place: a flocculation procedure, a sand filter, and a 1.0 micron microfilter. Remember that the town is poor and your design needs to provide a cost-effective solution. Your design may involve single-step or multiple-step methods.

4. Complete questions 2 and 3 in the Student Report.

TABLE 3.22: Water Measurements Before and After Flooding

Substance	Before flooding (mg/L)	After flooding (mg/L)	"Safe" levels (mg/L)	Health hazard or water-taste quality
Ca^{2+}	168	296	160	Contributes to water "hardness"
Mg^{2+}	31	185	15	Contributes to water "hardness"
Na^{+}	50	260	350	Dehydration
${CO_3}^{2-}$	367	500	100	Taste or alkalinity
${SO_4}^{2-}$	192	1794	300	Water taste
Cd^{2+}	.002	.018	.005	Kidney damage
Bacteria (*E. coli*)	0	24	0	Diarrhea, cramps, nausea, or headaches

TABLE 3.22: (continued)

Substance	Before flooding (mg/L)	After flooding (mg/L)	"Safe" levels (mg/L)	Health hazard or water-taste quality
Asbestos (million fibers/L) from rotting pipes	2	12	7	Increased risk of developing intestinal polyps
Human hair (million hairs/L)	16	48	3	None known, just disgusting

Jarny's Current Water Cleaning System

Jarny's current water cleaning system involves treating the water with a flocculent (a material that combines with large-sized particles in the water) and then letting the flocculent (with the large particle combinations) sink to the bottom so it can be removed. The remaining water is filtered through two filters: 1) sand, and then 2) a membrane with 1.0 micrometer diameter holes.

References

- http://maps.google.com
- Adapted from http://ga.water.usgs.gov/edu/earthgwdecline.html

Student Report

1. Use the water quality information in Table 1 to fill in Table 3 below.

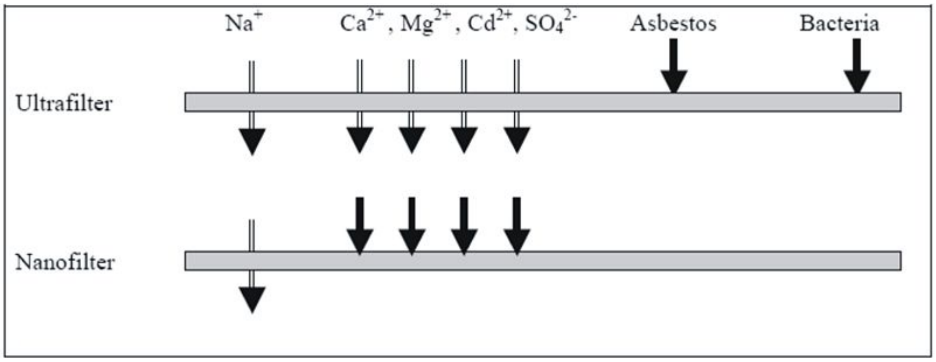
TABLE 3.23: **Substances Present at Unacceptable Levels**

Substance	**Amount over acceptable limit**	**Rank substances by size** (1 = largest) If there is a range, choose the size at the smallest end of the range Particles of similar size can have the same ranking	**Least expensive filter necessary**
Ca^{2+}	136 mg/L	4	nanofilter
Mg^{2+}	170 mg/L	4	nanofilter
$CO_3{}^{2-}$	400 mg/L	4	nanofilter
$SO_4{}^{2-}$	1494 mg/L	4	nanofilter
Cd^{2+}	0.013 mg/L	4	nanofilter
Bacteria (*E coli*)	24	2	microfilter
Asbestos	5	3	ultrafilter
Human hair	45 (between $40-300$ microns)	1	particle filter

2. The best filter or combination of filters to add to Jarny's water system are the following, in order:

A ultrafilter (filter with a pore size of < 0.1 microns) and then a nanofilter.

3. Draw your design showing the water and its contents before and after passing through each filter in your design.



Reflecting on the Guiding Questions: Teacher Instructions

You may want to have your students keep these in a folder to use at the end of the unit, or collect them after each lesson to see how your students' thinking is progressing.

Think about the activities you just completed. What did you learn that will help you answer the guiding questions? Jot down notes in the spaces below.

1. Why are water's unique properties so important for life as we know it?

What I learned in these activities:

What I still want to know:

2. How do we make water safe to drink?

What I learned in these activities:

What I still want to know:

3. How can nanotechnology help provide unique solutions to the water shortage?

What I learned in these activities:

What I still want to know:

4. Can we solve our global water shortage problems? Why or why not?

What I learned in these activities:

What I still want to know: