nanosense

NanoSense Curriculum Series | May 2008

Clear Sunscreen: How Light Interacts with Matter

NanoSense Curriculum Series

About the NanoSense Project

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

License Information

Attribution Information

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Electronic Versions of Materials

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

Contact Information

The NanoSense Project
Center for Technology in Learning. SRI International
333 Ravenswood Ave
Menlo Park, CA 94025
http://nanosense.org

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For Anyone Planning to Teach Nanoscience… Read This First!

Nanoscience Defined

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

Nanoscience is "Science-in-the-Making"

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

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

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

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

Challenges & Opportunities

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Final Words

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

References

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

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

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

Clear Sunscreen: Overview, Learning Goals & 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

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.

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		√
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.

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
	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	

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
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**		Animation Worksheet Reflection on Guiding	Prepare to present animations

Lesson	Teaching Days	Main Activities and Materials	Learning Goals	Assessment	Homework
		Discussion of Pre-Made Animations and Reflection on Guiding Questions		Questions	
Lesson 4 (continued)	*Day 3* *(animation creation only)*	Class Presentation and Discussion of Student Animations Reflection on 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
	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	

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

1. How the energies of different wavelengths of light interact differently with our skin and vision.
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.

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

1. How do “nano-sunscreens” differ from traditional sunscreens?
2. What is the best kind of sunscreen to use and why?
3. Should nanoproducts have special regulations associated with them?

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

1. Describe the mechanism of absorption and scattering by which light interacts with matter.
2. Describe how particle size, concentration and chemical / solvent identity (refractive index), 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 these objects.
4. 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 Learning Goals

	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*
Assessment	*Lab Results/ Initial Ideas Worksheet*	*Label Results/ Reflection Worksheet*	*Reflection Worksheet*	*Animation/ Reflection Worksheet*	*Consumer Pamphlets/ Quiz*
Learning Goals					
Students will understand…					
EU 1. How the energies of different wavelengths of light interact differently with different kinds of matter.	•		•	•	•
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.	•	•		•	•

Learning Goals	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*
Assessment	*Lab Results/ Initial Ideas Worksheet*	*Label Results/ Reflection Worksheet*	*Reflection Worksheet*	*Animation/ Reflection Worksheet*	*Consumer Pamphlets/ Quiz*
Students will be 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.		•		•	•
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

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 o UV Protection Lab Activity o Summary of Sun Radiation • L2 o Light Scattering by 3 Sunscreens handout o Sunscreen Ingredient Activity o FDA Approved Sunscreen Ingredients • L4 o Reading: Scattering of Light by Particles o Ad Campaign Project w/ ChemSense animation • L5 o Consumer Choice Pamphlet project o Student Quiz
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

Physics

Unit Topic	Chapter Topic	Subtopic	Clear Sunscreen Lessons	Specific Materials
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 Physics	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

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: o Sunscreen ingredients Activity o Light Scattering by Three Sunscreens o Reflection on the Guiding Questions • L3: o Reading: Absorption of Light by Matter o Reflecting on the Guiding Questions • L4: o Reading: Scattering of Light by Particles o Sunscreens & Sunlight Animations • L5: Ad Campaign Project

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 Campaign Project

[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.

List of Sunscreen Products that Use Nanoparticulate Ingredients

(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 & 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)

	Organic Ingredients (e.g. PABA)	**Inorganic Ingredients (e.g. Classic Zinc Oxide used by lifeguards)**
Chemical Structure	Similar or $\boxed{\text{Different}}$ How: Nano ingredients are small ionic clusters while organic ingredients are molecules.	$\boxed{\text{Similar}}$ 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 $\boxed{\text{Different}}$ How: Organic ingredients each block a small part of the UV spectrum (generally UVB) while nano ingredients block almost the whole thing,	$\boxed{\text{Similar}}$ or Different How: Both nano ingredients and traditional inorganic ingredients block almost the whole UV spectrum.
Way Light is Blocked	$\boxed{\text{Similar}}$ 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)	$\boxed{\text{Similar}}$ or Different How: Both nano and inorganic ingredients block UV light via absorption.
Appearance on the Skin	$\boxed{\text{Similar}}$ or Different How: Both nano and organic ingredients appear clear on the skin.	Similar or $\boxed{\text{Different}}$ 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 $\approx \frac{1}{2}\lambda$ 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) <u>and</u> sunscreen appears clear on the skin.

Unit Overview

Student Materials

Contents

Name____________________________________ Date_______________________ Period ______

Clear Sunscreen: Pretest

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.

	Organic Ingredients (e.g. PABA)	Inorganic Ingredients (e.g. Classic Zinc Oxide used by lifeguards)
Chemical Structure	Similar or Different How:	Similar or Different How:
Kinds of Light Blocked	Similar or Different How:	Similar or Different How:
Way Light is Blocked	Similar or Different How:	Similar or Different How:
Appearance on the Skin	Similar or Different How:	Similar or Different How:

2. Briefly describe one benefit and one drawback of using a sunscreen that contains “nano” ingredients.

3. What determines if a sunscreen appears white or clear on your skin?

4. How do you know if a sunscreen has “nano” ingredients?

Name__________________________________ Date______________________ Period ______

Clear Sunscreen: Posttest

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.

	Organic Ingredients (e.g. PABA)	Inorganic Ingredients (e.g. Classic Zinc Oxide used by lifeguards)
Chemical Structure	Similar or Different How:	Similar or Different How:
Kinds of Light Blocked	Similar or Different How:	Similar or Different How:
Way Light is Blocked	Similar or Different How:	Similar or Different How:
Appearance on the Skin	Similar or Different How:	Similar or Different How:

2. Briefly describe one benefit and one drawback of using a sunscreen that contains “nano” ingredients.

3. What determines if a sunscreen appears white or clear on your skin?

4. How do you know if a sunscreen has “nano” ingredients?

Lesson 1:
Introduction to Sun Protection

Teacher Materials

Contents

Introduction to Sun Protection: 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:

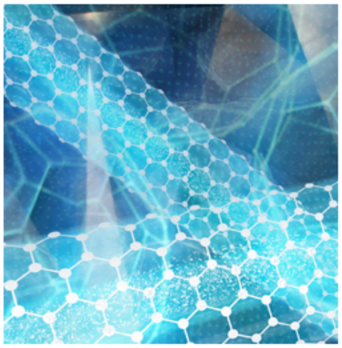
(Numbers correspond to learning goals overview document)

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

Introduction & 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	
	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. If there is time, combine the whole class's data into one super graph.	10 min	
Student Homework: Complete the Conclusion section of the lab	*30 min*	



Sun Protection

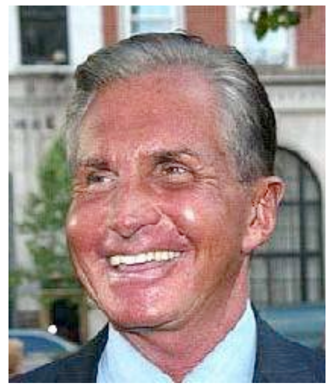
Understanding the Danger

NanoSense
the basic sense behind nanoscience

Why use sunscreen?

Too Much Sun Exposure is Bad for Your Body

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



Sources: http://www.oasishospital.org/previousnews.html; http://wohba.com/archive/2005_03_01_archive.html

Skin Cancer Rates are Rising Fast

Skin cancer:

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

Probability of getting skin cancer

Causes of the increase:

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

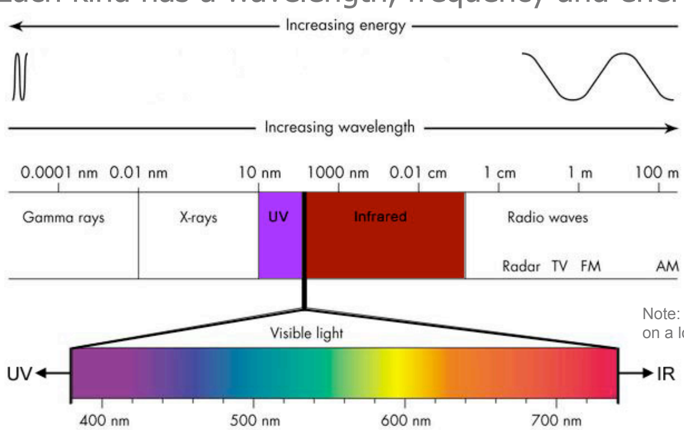
Sources: http://www.msnbc.msn.com/id/8379291/site/newsweek/ ; http://www.skincarephysicians.com/skincancernet/whatis.html; http://www.msu.edu/~aslocum/sun/skincancer.htm

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

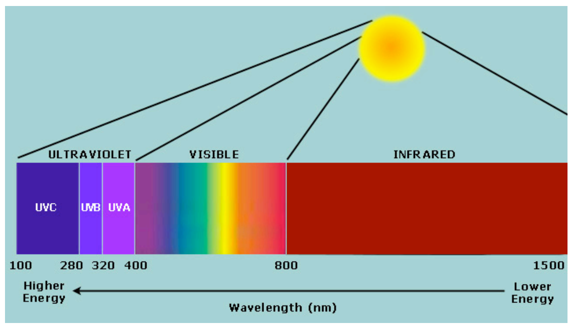


Note: Diagram drawn on a logarithmic scale

Source: Adapted from http://www.mhhe.com/physsci/astronomy/arny/instructor/graphics/ch03/0305.html

The Sun's Radiation Spectrum I

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

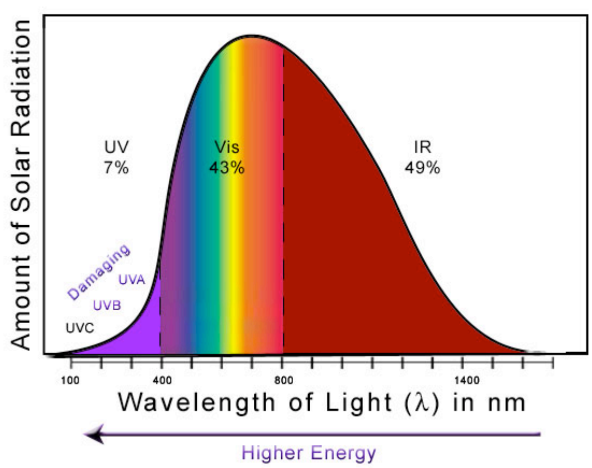


- **Higher energy radiation can damage our skin**

Source: http://www.arpansa.gov.au/is_sunys.htm

The Sun's Radiation Spectrum II

- **How much UV, Vis & IR does the sun emit?**

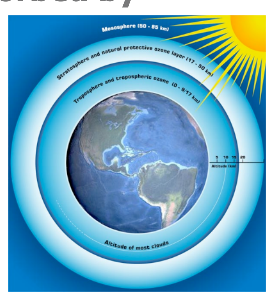


Source: http://www.arpansa.gov.au/is_sunys.htm

Does all the radiation from the sun reach the earth?

The Earth's Atmosphere Helps Protect Us

- **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

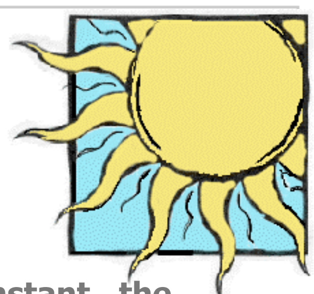


- **Challenge Questions**
  1. What happens if the Ozone layer is partially or completed destroyed?
  2. Why are we concerned about UV, but not IR or visible light?

Source: http://www.space.gc.ca/asc/img/atmosphere-couche.jpg

How can the sun's rays harm us?

Sun Rays are Radiation



- 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

Source: http://www.pueblo.gsa.gov/cic_text/health/sun_uv/sun-uv-you.htm

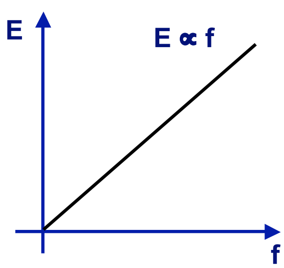
Radiation Energy I

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

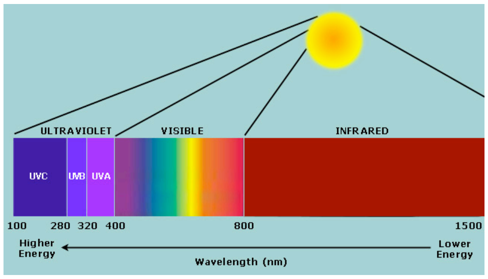
- This relates not only to how much energy is in each packet but also to the total number of packets arriving at a given location (such as our skin)

- 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

Source: http://www.epa.gov/sunwise/uvwhat.html

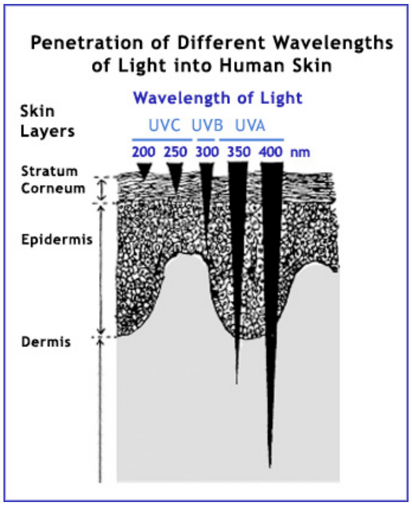
Skin Damage I

- **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**



Source: http://www.arpansa.gov.au/is_sunys.htm

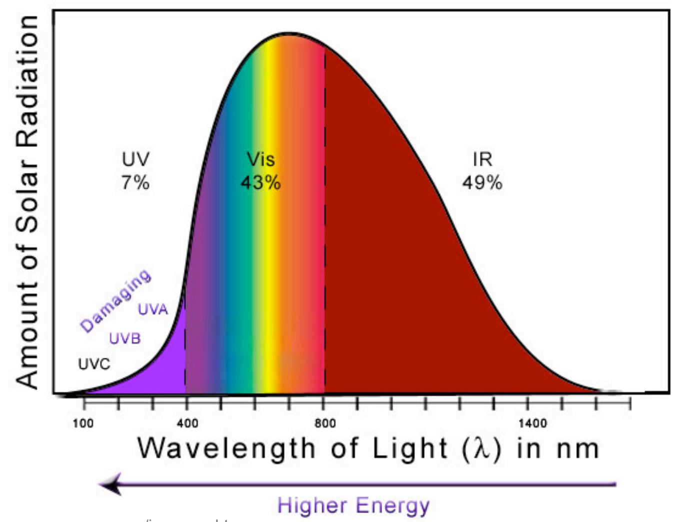
Skin Damage II



- **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**

Source: 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.

Sun Radiation Summary I



Source: http://www.arpansa.gov.au/is_sunys.htm

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?
UVC	~200-290 nm (Short-wave UV)	Increasing Energy 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
Vis	~400-800 nm	Lower Energy	~43 %	None Currently Known	Yes
IR	~800-120,000 nm Increasing Wavelength	Lowest Energy	~49%	Heat Sensation (high λ IR)	No

NanoSense 19

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

Source: http://www.niehs.nih.gov/oc/factsheets/genes/home.htm

NanoSense 20

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?

Sun Protection: 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.
- 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: ~100-280 nm; UVB: ~280-315 nm; UVC ~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?**

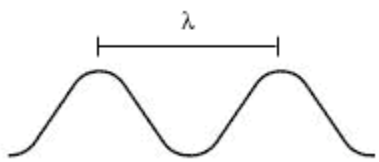
We are concerned about UV radiation because it is higher in energy than IR and visible radiation (this will be covered in more detail in the following slides). Even though there is less of it, it has the potential to damage humans, while it is currently thought that IR and visible radiation do not.

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 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 ~225,563,909 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 (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 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.

1. What are the most important factors to consider in choosing a sunscreen?	**How sure are you that this is true?** Not Sure	Kind-of Sure	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	Kind-of Sure	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	Kind-of Sure	Very Sure	**End of Unit Evaluation**

Ultra-Violet (UV) Protection Lab Activity: Teacher Instructions & 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 300ºF.
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.

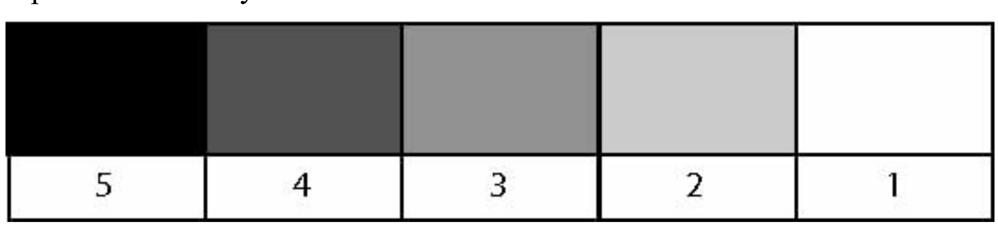
- ❒ Obtain eight small paper cups. Obtain a small sample of each of the substances you have chosen. Label each cup with the name of the substance.

  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.



Opacity Guide

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_________**

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.

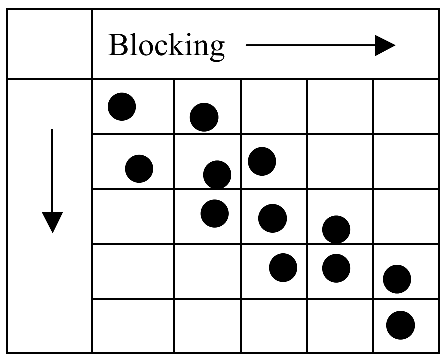
UV Blocking Ability → / Opacity ↓	No Blocking (10)	Low Blocking (8)	Medium Blocking (6)	High Blocking (4)	Total Blocking (2)
5 Fully Transparent					
4					
3					
2					
1 Fully Opaque					

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 2nd or the 3rd 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 2nd or the 3rd 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.

Sunscreen Smear Sheet

Sample:	Sample:	Sample:	Sample:

Sample:	Sample:	Sample:	Sample:

Sunscreen Smear Sheet

Sample:	Sample:	Sample:	Sample:

Sample:	Sample:	Sample:	Sample:

Lesson 1:
Introduction to Sun Protection

Student Materials

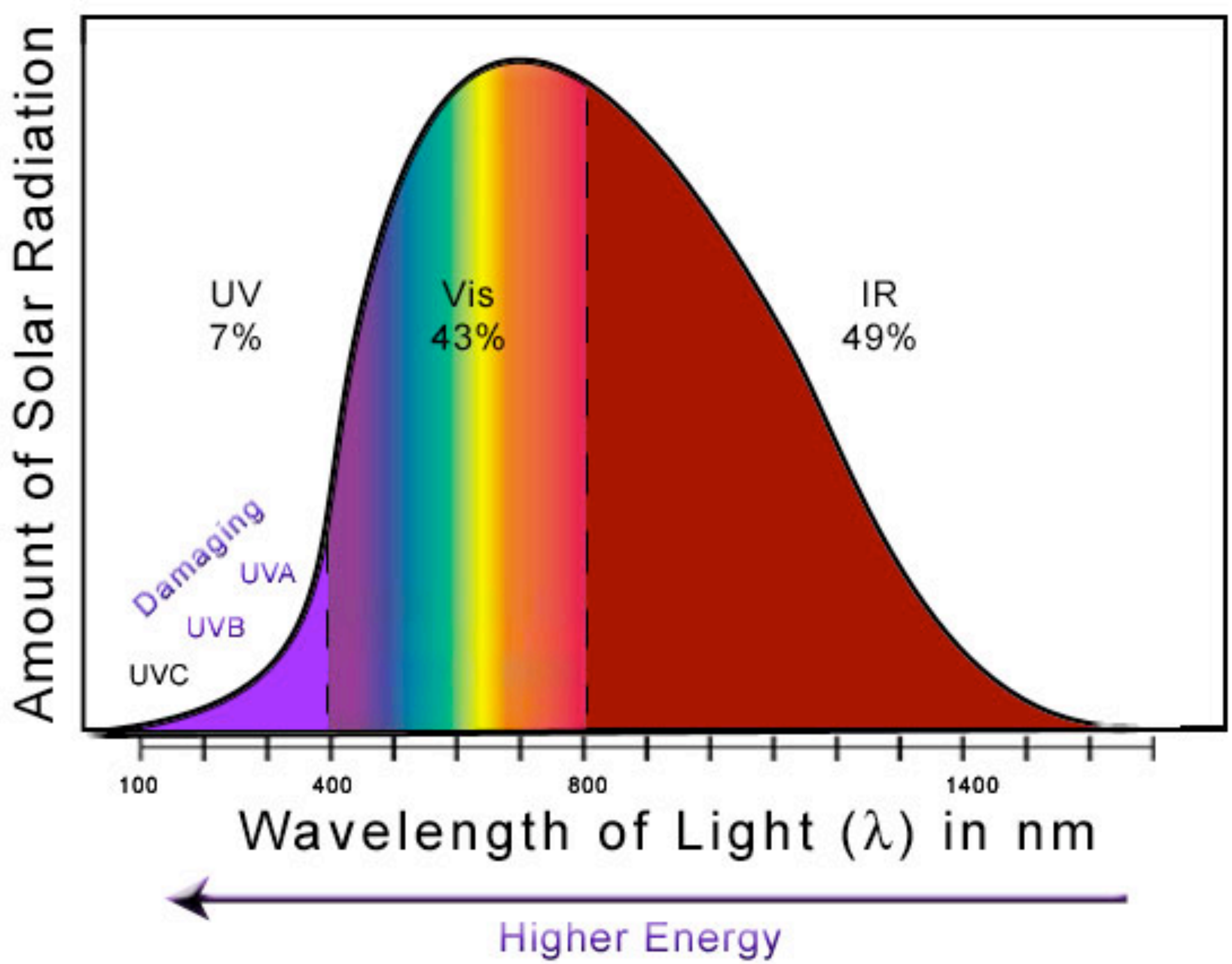
Contents

Summary of Radiation Emitted by the Sun: Student Handout

Chart of Different Kinds of Solar Radiation

Radiation Type	Characteristic Wavelength (λ)	Energy per Photon	% of Total Radiation Emitted by Sun	Effects on Human Skin	Visible to Human Eye?
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
Visible	~400-800 nm	Lower Energy	~43 %	None Currently Known	Yes
IR	~800-120,000 nm	Lowest Energy	~49%	Heat Sensation (high λ IR)	No

Graph of Radiation Emitted by the Sun by Wavelength



Name________________________________ **Date**____________________ **Period** _________

Clear Sunscreen Initial Ideas: Student Worksheet

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.

1. What are the most important factors to consider in choosing a sunscreen?	**How sure are you that this is true?** Not So Sure	Kind-of Sure	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 So Sure	Kind-of Sure	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 So Sure	Kind-of Sure	Very Sure	**End of Unit Evaluation**

Name_______________________________ Date________________________ Period ______

Ultra-Violet (UV) Protection Lab Activity: Student Instructions & Worksheet

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?

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 can not 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.

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.

Materials

- Assorted white substances varying in opacity (for example: different sunblocks, sunscreens, sungels, glass pieces, white tee-shirts of varying thickness, white tissue paper, white paper of varying thickness, laundry detergent, white paint, white face makeup)
- Eight paper cups
- One micro spoon
- Sunscreen Smear Sheet
- Black construction paper (for judging opacity of white substances)
- UV light source
- UV sensitive bead testers
- UV bead color guide
- Cotton swabs (for apply sunscreen to the Sunscreen Smear Sheet)
- Alcohol wipes (for cleaning sunscreen off the Sunscreen Smear Sheet)

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.

Opacity Guide

Part III: Test the UV Blocking

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

- ❒ 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.
- ❒ Repeat for each of your substances.

Data Chart

Initial C1 Bead Color Number________ **Initial C2 Bead Color Number_________**

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

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.

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.

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.

	Blocking →				
↓					

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

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

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

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?

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.

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.)

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

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

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

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?

Lesson 2:
All About Sunscreens

Teacher Materials

Contents

All About Sunscreens: Teacher Lesson Plan

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.

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
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 & 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.

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 & 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 nm) and UVA (320 – 400 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?

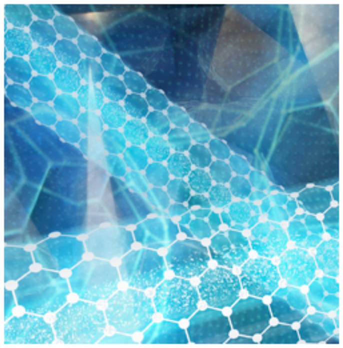
Different sunscreen ingredients prevent different wavelengths of light from reaching the skin. They block different parts of the UV spectrum. (A secondary reason is that high concentrations of chemicals on the skin can cause irritation, this is why when the FDA approves a sunscreen ingredient, it also 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

NanoSense
the basic sense behind nanoscience

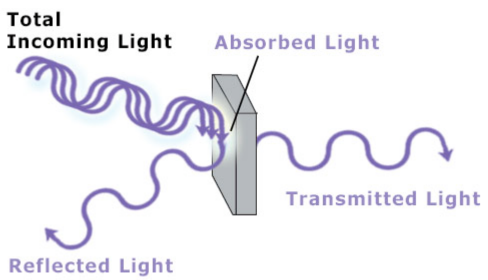
What do Sunscreens Do?

- Sunscreens are designed to protect us by preventing UV rays from reaching our skin
- But what does it mean to **"block"** UV rays?

Source: Image adapted from http://www.ashevilleparc.org/files/sssd1small.jpg

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



Transmission
Reflection
+ Absorption
100%

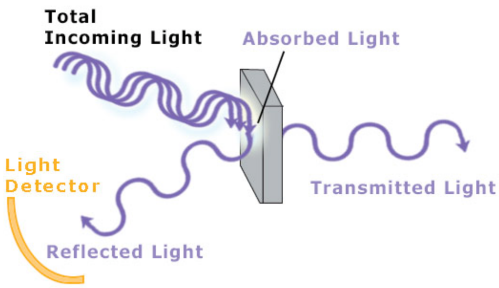
- If we say that light is "blocked" it means that it is either absorbed or reflected by the material

Source: Original Image

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

- **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



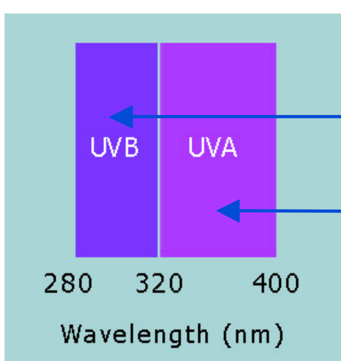
We detected little UV light reflected – so we know that the sunscreens block via absorption

Source: Original Image

A Brief History of Sunscreens: The Beginning

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

WWII soldiers in the sun



The sunburn causing rays were labeled as UV-B

Longer wavelengths in the UV range were called UV-A

Sources: http://www.bbc.co.uk/wiltshire/content/articles/2005/05/05/peoples_war_feature.shtml
http://www.arpansa.gov.au/is_sunys.htm

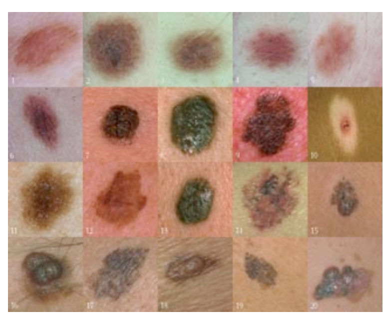
A Brief History of Sunscreens: The SPF Rating

- **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

Sources: http://www.shop.beautysurg.com/ProductImages/skincare/14521.jpg and http://www.shop.beautysurg.com/ProductImages/skincare/14520.jpg

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**



Twenty different skin cancer lesions

- ***NEW:* The FDA has just proposed a 4-star UVA rating to be included on sunscreen labels!**

Low ★★★★ Med ★★★★ High ★★★★ Highest ★★★★

Source: http://www.cs.wright.edu/~agoshtas/fig8.jpg

NanoSense 9

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

NanoSense 10

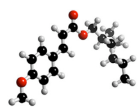
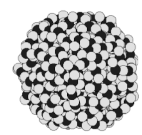
Know Your Sunscreen: Look at the Ingredients

- **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

Source: Original Image

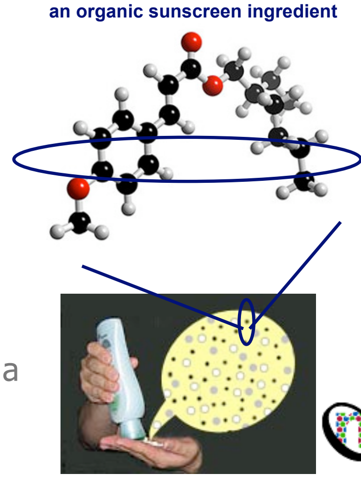
Sunscreen Ingredients Overview

	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 λ < critical value
Appearance	Clear	Large clusters = White Small clusters = Clear

Organic Ingredients: The Basics

- **Organic = Carbon Compounds**
  - H, O & 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)

Octyl methoxycinnamate ($C_{18}H_{26}O_3$)
an organic sunscreen ingredient

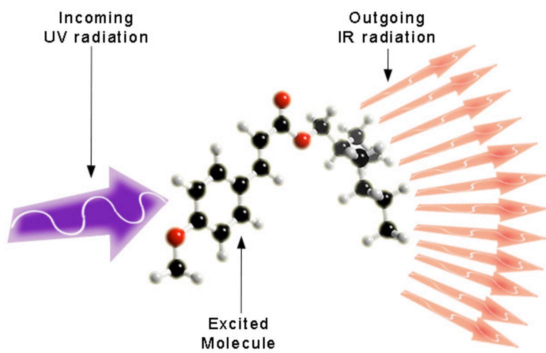


Sources: http://www.3dchem.com/molecules.asp?ID=135# and original image

Organic Ingredients: UV Blocking

Organic Sunscreen Ingredients can absorb UV rays

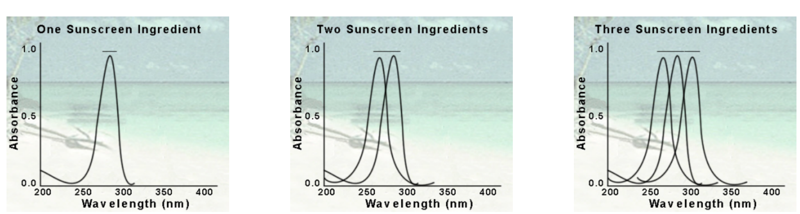
1. Molecules capture energy from the sun's UV rays
2. The energy give the molecule thermal motion (vibrations and rotations)
3. The energy is re-emitted as harmless long wave IR



Source: Adapted from http://www.3dchem.com/molecules.asp?ID=135#and http://members.aol.com/WSRNet/tut/absorbu.htm

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

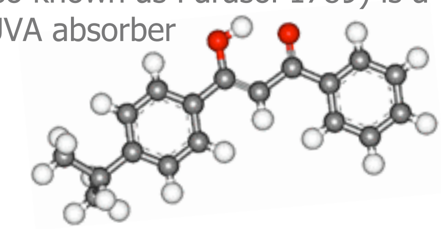


Source: Graphs adapted from http://www.aims.gov.au/pages/research/projects/sunscreens/pages/sunscreens02.html

NanoSense 15

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 (also known as Parasol 1789) is a good FDA approved UVA absorber

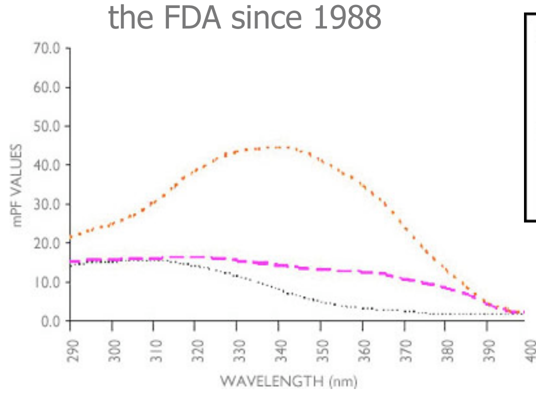


Source: http://jchemed.chem.wisc.edu/JCEWWW/Features/MonthlyMolecules/2004/Oct/JCE2004p1491fig4.gif

NanoSense 16

------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



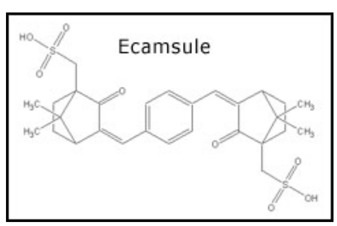


Image Sources: http://www.anthelios.com/anthelios-medical_prof.html and http://en.wikipedia.org/wiki/Image:Mexorylsx.png

NanoSense 17

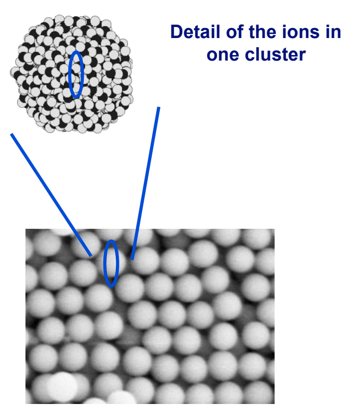
How are inorganic sunscreen ingredients different from organic ones?

How might this affect the way they absorb UV light?

NanoSense 18

Inorganic Ingredients: The Basics

- **Atoms Involved**
  - 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

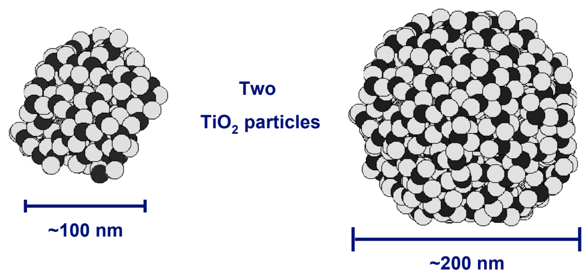


Group of TiO_2 particles

Source: http://www.microspheres-nanospheres.com/Images/Titania/TIO2%20P7.jpg and image adapted from http://www.cse.clrc.ac.uk/msi/projects/ropa.shtml

Inorganic Ingredients: Cluster Size

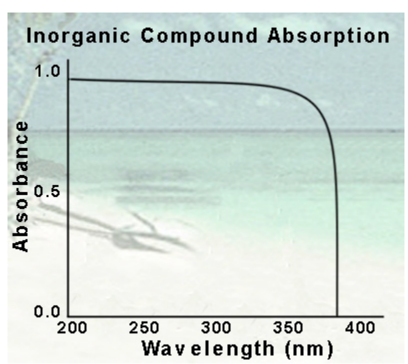
- **Inorganic ingredients come in different cluster sizes (sometimes called "particles")**
  - Different number of ions can cluster together
  - Must be a multiple of the formula unit
    - ZnO always has equal numbers of Zn and O atoms
    - TiO_2 always has twice as many O as Ti atoms



Source: Images adapted from http://www.cse.clrc.ac.uk/msi/projects/ropa.shtml

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 ~380nm
  - How is the absorption pattern different than for organics?



Source: Graph adapted from http://www.aims.gov.au/pages/research/projects/sunscreens/pages/sunscreens02.html

NanoSense 21

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

Source: http://www.loc.gov/rr/scitech/mysteries/images/sunscreen2.jpg

NanoSense 22

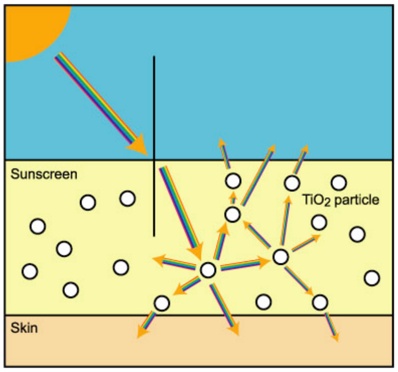
Appearance Matters

- 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

Source: http://www.4girls.gov/body/sunscreen.jpg

Why Do They Appear White? I

- **Traditional ZnO and TiO_2 clusters are large**
  - (> 200nm)
- **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!

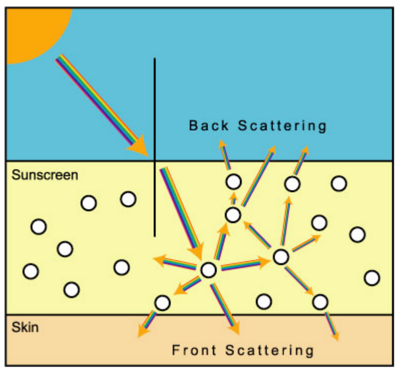


Source: Original Image

Why Do They Appear White? II

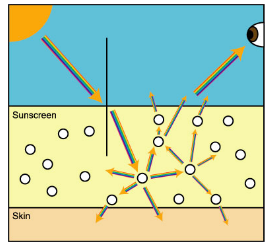
Light eventually goes in one of two directions:

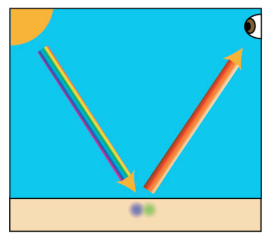
1. **Back the way it came (back scattering)**
   - Back-scattered light is reflected
2. **Forwards in the same general direction it was moving (front scattering)**
   - Front-scattered light is transmitted



Why Do They Appear White? III

- **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

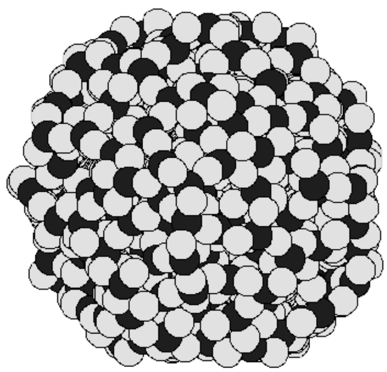


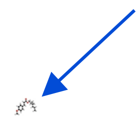


Why don't organic sunscreen ingredients scatter visible light?

Source: Adapted from http://www.loc.gov/rr/scitech/mysteries/images/sunscreen2.jpg

Organic Sunscreen Molecules are Too Small to Scatter Visible Light





200 nm TiO_2 particle (Inorganic)

Methoxycinnamate (<10 nm) (Organic)

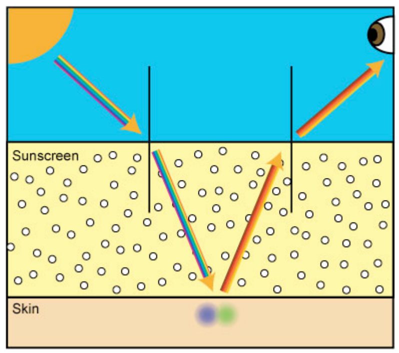
Source: Images adapted from http://www.cse.clrc.ac.uk/msi/projects/ropa.shtml and http://www.3dchem.com/molecules.asp?ID=135#

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

Source: Adapted from http://www.loc.gov/rr/scitech/mysteries/images/sunscreen2.jpg

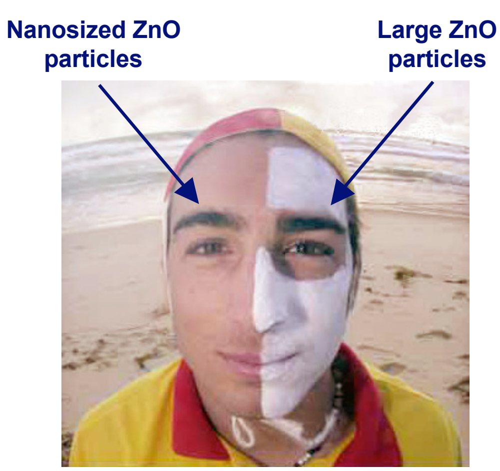
Nanosized Inorganic Clusters

- **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



Source: Graph adapted from http://www.aims.gov.au/pages/research/projects/sunscreens/pages/sunscreens02.html

Nano-Sunscreen Appears Clear



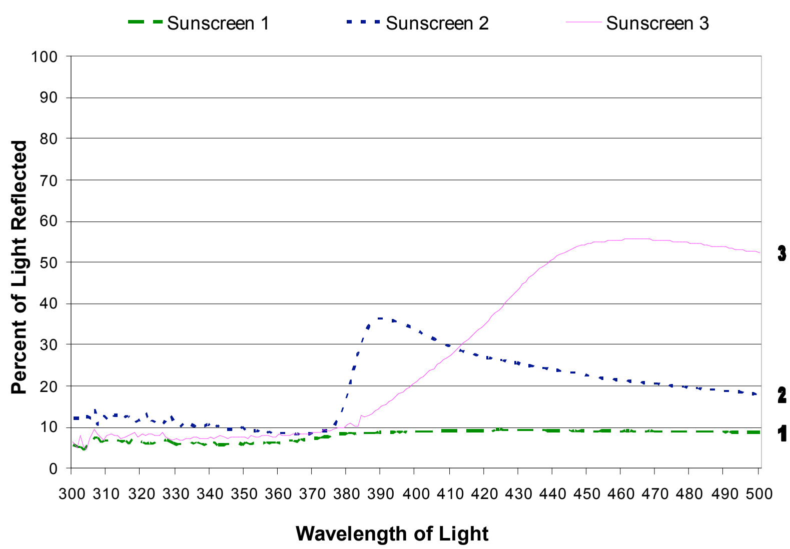
Source: http://www.science.org.au/sats2003/images/barber-slide3.jpg

Let’s Look at Some Real Data…

- **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

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

Light Reflected by Three Sunscreens



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

Source: http://www.smalltimes.com/images/st_advancednanotech_inside_.jpg

NanoSense 35

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?

All About Sunscreens: Teacher Notes

Overview

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 not 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 photo-stable (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 & 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 <u>not</u> 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 & Sunlight Animations: Teacher Instructions & 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 & 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 & 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.

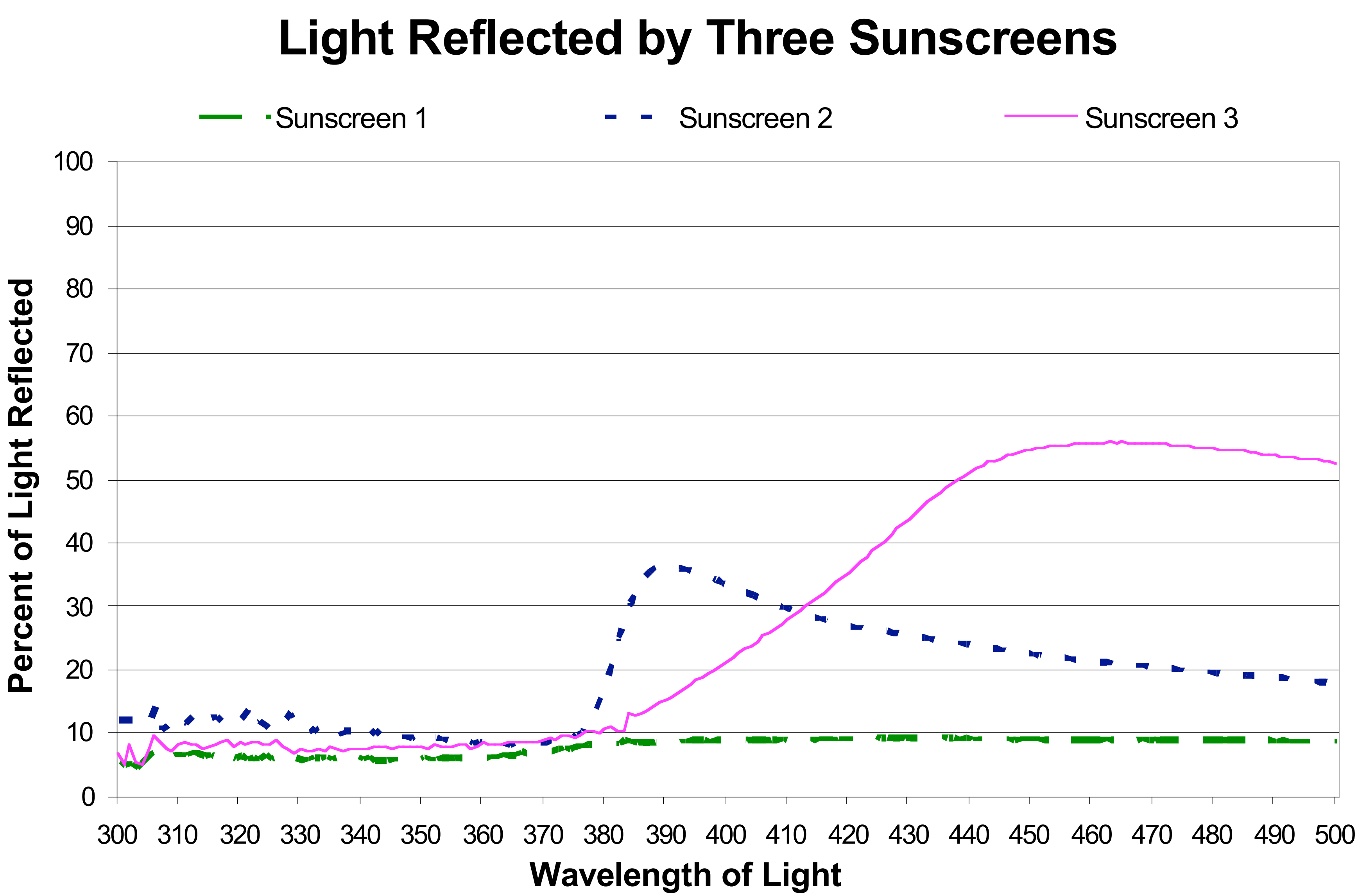
Instructions

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?

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)
# 3	Significant scattering 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
Sunscreen 1
Sunscreen 2
Sunscreen 3
Percent of Light Reflected
0
10
20
30
40
50
60
70
80
90
100
300
310
320
330
340
350
360
370
380
390
400
410
420
430
440
450
460
470
480
490
500
Wavelength of Light

Reflecting on the Guiding Questions: Teacher Instructions & Answer Key (Lesson 2)

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 TiO2 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: 380nm (ZnO) or 365 nm (TiO2).

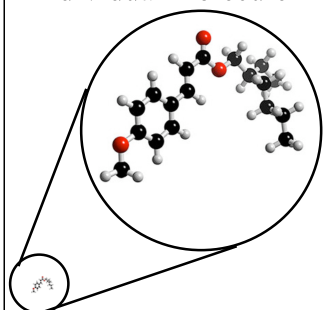
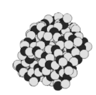
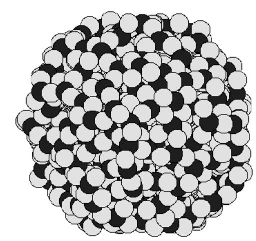
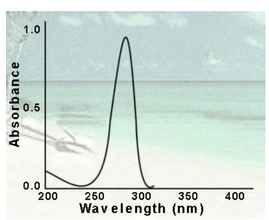
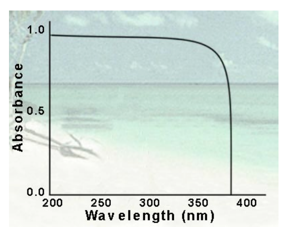
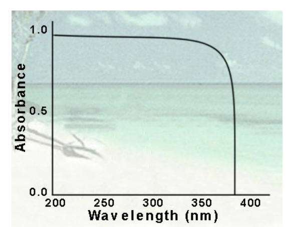
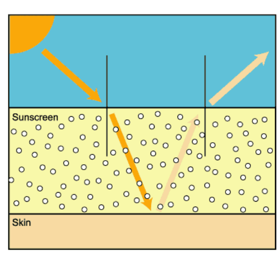
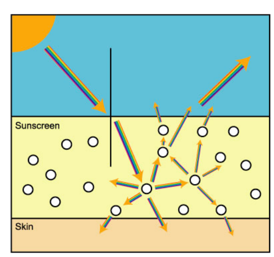
What I still want to know:

Lesson 2: All About Sunscreens

Student Materials

Contents

Overview of Sunscreen Ingredients: Student Handout

	Organic Ingredients	**Inorganic Ingredients (Nano)**	**Inorganic Ingredients (Large)**
Atoms Involved	Carbon, Hydrogen, Oxygen, Nitrogen	Zinc, Titanium, Oxygen	Zinc, Titanium, Oxygen
Structure (not drawn to scale)	Individual molecule 	Cluster ~100 nm in diameter 	Cluster > 200 nm in diameter 
Interaction with UV light	Absorb specific λ 	Absorb all UV < critical λ 	Absorb all UV < critical λ 
Absorption Range	Parts of UVA or UVB spectrum	Broad spectrum UVA and UVB	Broad spectrum UVA and UVB
Interaction with Visible light	None	Minimal Scattering 	Much Scattering 
Appearance	Clear	Clear	White

Name________________________________ Date_________________________ Period ______

Light Reflection by Three Sunscreens: Student Worksheet

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

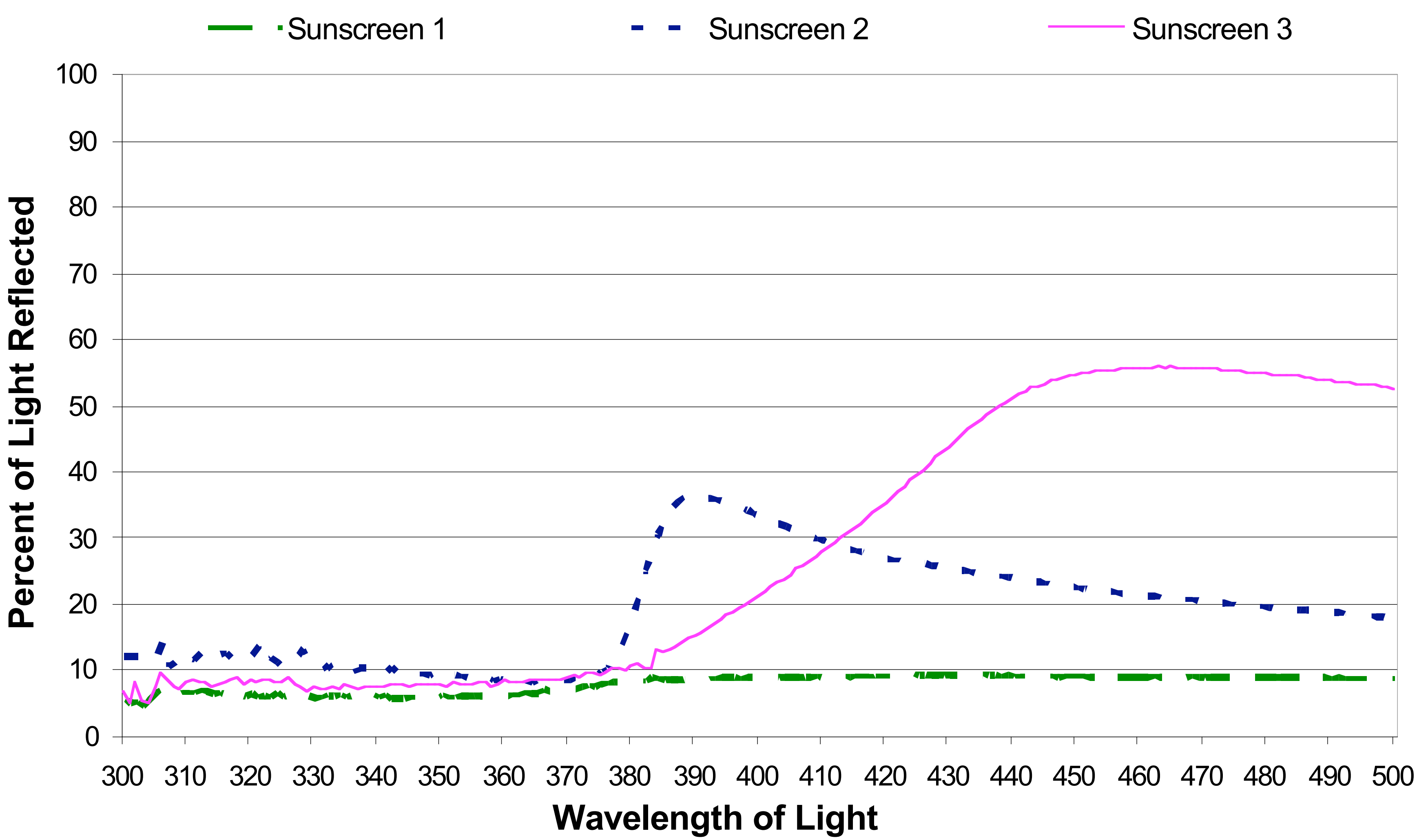
Use the graph to answer the following questions for each sunscreen in the chart on the next page:

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?

Light Reflection by Three Sunscreens Chart

	Appearance	Size	UV Blocking	Identity (w/ reason)
# 1				
# 2				
# 3				

Light Reflected by Three Sunscreens



Sunscreen Ingredients Activity: Student Instructions & Worksheet

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.*

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.

Data Chart

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

Questions

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

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

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

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

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?

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?

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

Summary of FDA Approved Sunscreen Ingredients: Student Handout

	λ range (nm)	Protection Against		Possible Allergies	Other Issues
		UVB 280-320 nm	UVA 320-400 nm		
Organic Ingredients					
PABA derivatives					
Padimate O (Octyl dimethyl PABA)	295-340	Good	Little	Yes	-
PABA (p-aminobenzoic acid)	200-320	Good	Little	Yes	Greasy, Stains
Cinnamates					
Octinoxate (Octyl methoxycinnamate) (OMC) (Parasol MCX)	295-350	Good	Little	Yes	-
Cinoxate	280-310	Good	Little	Yes	-
Salicylates					
Homosalate	295-340	Good	Little	Yes	-
Octisalate (Octyl salicylate)	295-330	Good	Little	Yes	-
Trolamin salicylate	260-355	Good	Little	Yes	-
Benzophenones					
Oxybenzone (Benzophenone-3)	295-375	Good	Some	Yes	-
Sulisobenzone (Benzophenone-4)	260-375	Good	Some	Yes	Hard to solubilize
Dioxybenzone (Benzophenone-8)	250-390	Good	Some	Yes	Hard to solubilize
Other Organics					
Ensulizole	290-340	Good	Little	Yes	-
Octocrylene	295-375	Good	Little	Yes	-
Menthyl anthranilate (Meradimate)	295-380	Good	Some	Yes	-
Avobezone (Parsol 1789) (Butyl methoxydibenzoyl methane)	295-395	Good	Good	Yes	If not well formulated, loses potency
NEW Ecamsule (Mexoryl SX)	310-370	Some	Good	Yes	Water-soluble
Inorganic Ingredients					
Titanium Dioxide	upto 365	Good	Good	No	-
Zinc Oxide	upto 380	Good	Good	No	-

Name__________________________________ Date______________________ Period ______

Reflecting on the Guiding Questions: Student Worksheet

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:

What I still want to know:

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

What I learned in this activity:

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:

What I still want to know:

Lesson 3:
How Sunscreens Block: The Absorption of UV Light

Teacher Materials

Contents

How Sunscreens Block: The Absorption of UV Light: 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)

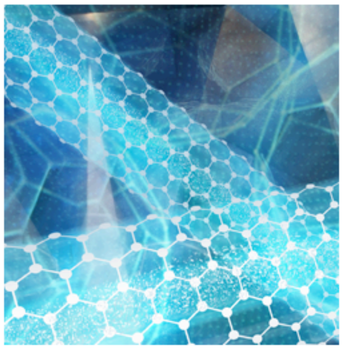
Students will be able to:

(Numbers correspond to learning goals overview document)

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

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
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

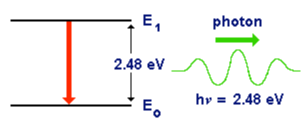
The Absorption of UV Light

NanoSense
the basic sense behind nanoscience

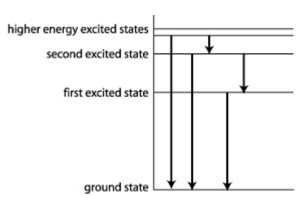
Prelude: Emission of Light by Atoms

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

Single electron falling from energy level E1 to E0



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



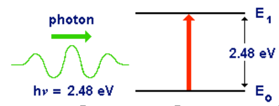
Electronic transitions and visible emission spectrum for a Helium atom

Sources: Images adapted from http://members.aol.com/WSRNet/tut/absorbu.htm, http://csep10.phys.utk.edu/astr162/lect/light/absorption.html

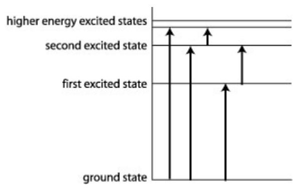
Prelude: Absorption of Light by Atoms

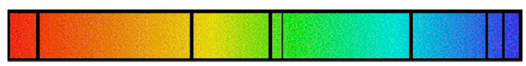
- **Absorption is just the reverse**
  - Only a photon with energy exactly corresponding to the energy of transition of an electron can be absorbed

Single electron transition
From E_0 to E_1



- **The different transitions produce absorption spectrums of discrete lines**



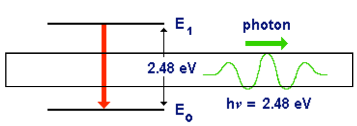


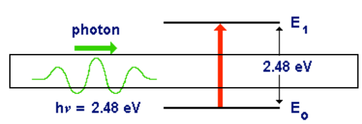
Electronic transitions and visible absorption spectrum for a Helium atom

Sources: http://members.aol.com/WSRNet/tut/absorbu.htm, http://csep10.phys.utk.edu/astr162/lect/light/absorption.html

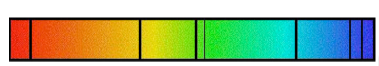
Prelude: Emission versus Absorption

Emission	Absorption
• Energy released at specific wavelengths	• Energy taken in from specific wavelengths





• Emission spectrum only shows wavelengths emitted	• Absorption spectrum shows all wavelengths except those absorbed

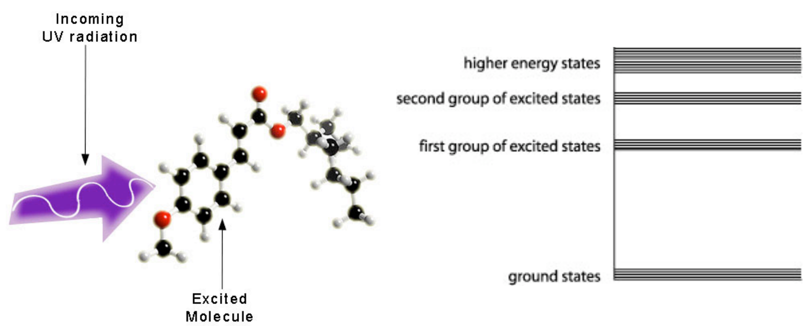


Sources: Images adapted from http://members.aol.com/WSRNet/tut/absorbu.htm, http://csep10.phys.utk.edu/astr162/lect/light/absorption.html

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
  - Each kind of vibration / rotation = different energy state
- Many more energy transitions possible



Source: Image adapted from http://www.3dchem.com/molecules.asp?ID=135#

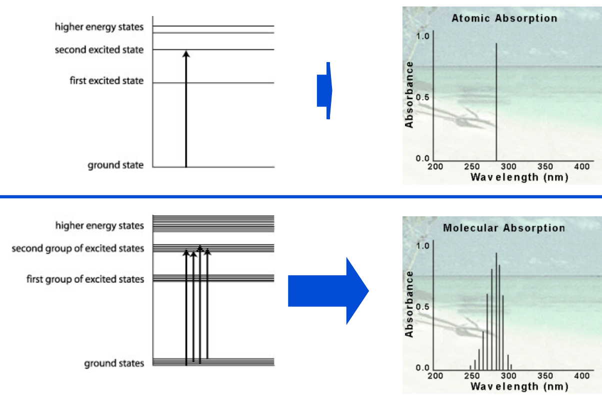
NanoSense 7

Organic Molecules: Absorption

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

Atomic Absorption

Molecular Absorption



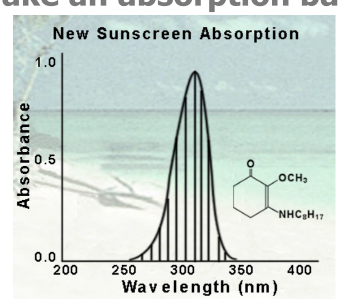
Source: http://www.nptel.iitm.ernet.in/courses/IITMadras/CY101/lecture16new/lecture16.htm

NanoSense 8

Organic Molecules: Absorption Curve

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

Absorption range for a new sunscreen molecule under testing



Range: 255 – 345 nm

Peak: 310 nm

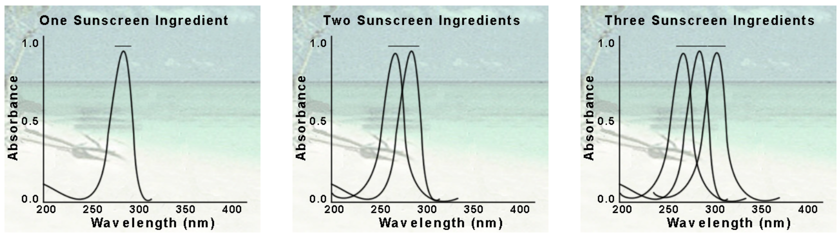
- **Peak absorption and absorption range vary by molecule**
  - Molecules are usually strong UVB or UVA absorbers but not both

Source: http://www.aims.gov.au/pages/research/projects/sunscreens/images/graph02-2a.jpg

NanoSense 9

Organic Molecules: UV Protection

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



- Using more than one kind of molecule gives broader protection

Source: Graphs adapted from http://www.aims.gov.au/pages/research/projects/sunscreens/pages/sunscreens02.html

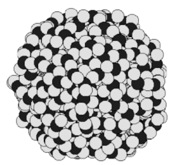
NanoSense 10

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

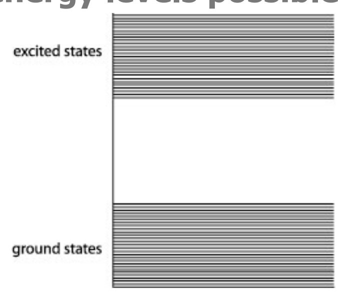
NanoSense 11

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**



~200 nm TiO_2 particle

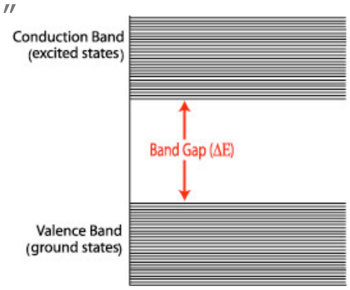


Source: Images adapted from http://www.cse.clrc.ac.uk/msi/projects/ropa.shtml

NanoSense 12

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"



Source: Original Image

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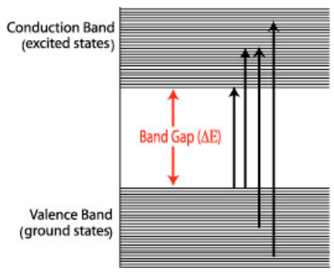
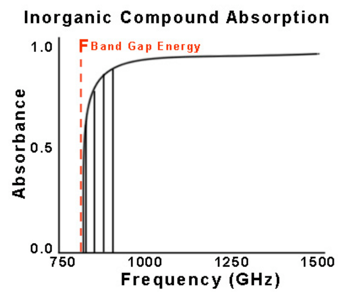
Inorganic Compounds: Absorption II

- **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



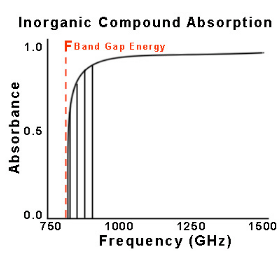


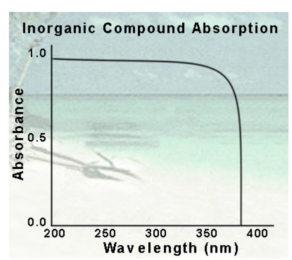
Source: Original Images

NanoSense 14

Inorganic Compounds: Absorption Curve

- **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**



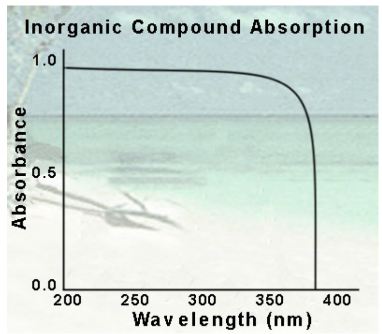


- **Absorption curves have sharp cutoffs at this λ**
  - Cutoff λ is characteristic of the kind of compound
  - Doesn't depend on size of the cluster

Source: Graph adapted from http://www.aims.gov.au/pages/research/projects/sunscreens/pages/sunscreens02.html

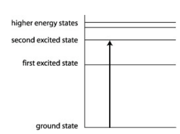
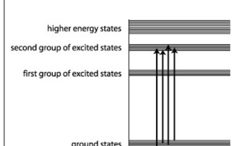
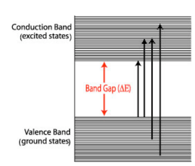
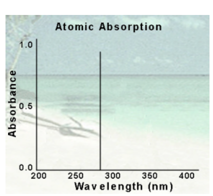
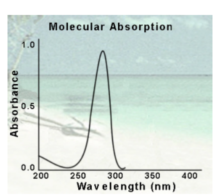
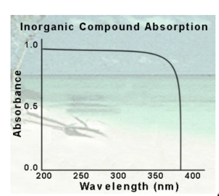
Inorganic Compounds: UV Protection

- **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)



Source: Graph adapted from http://www.aims.gov.au/pages/research/projects/sunscreens/pages/sunscreens02.html

Absorption Summary

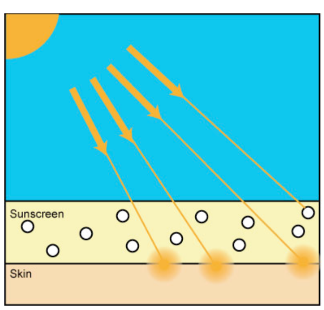
	Atoms	Organic Molecules	Inorganic Compounds
Energy Levels			
Absorption Spectrum			

Challenge Question:

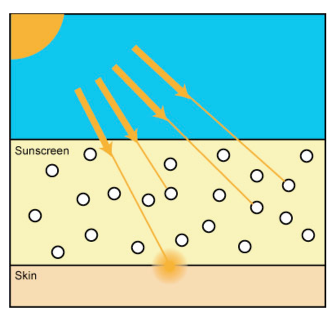
Can sunscreens absorb all of the UV light that shines on our skin?

Answer: It Depends I

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



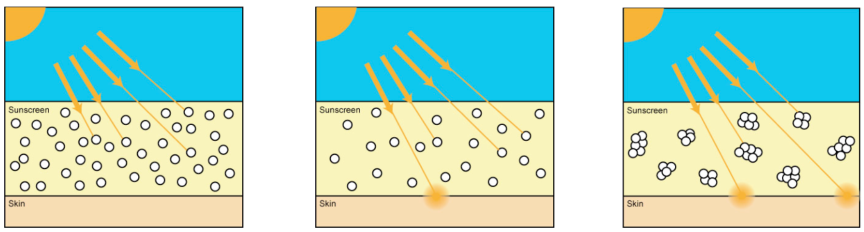
Thin Layer of Application



Thick Layer of Application

Answer: It Depends II

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



High Concentration
High Dispersion

High Dispersion
Low Concentration

High Concentration
Low Dispersion

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

How Sunscreens Block: The Absorption of UV Light: 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.

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 ~280-320 nm while the UVA range is ~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 (λ=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*λ).

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 (~320-400 nm) and does include the entire UVB (~280-320 nm) range.

The energy of the band gap of $Ti0_2$ 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 & Answer Key (Lesson 3)

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: 380nm (ZnO) or 365 nm (TiO_2).

What I still want to know:

Lesson 3:
How Sunscreens Block: The Absorption of UV Light

Student Materials

Contents

Absorption of Light by Matter: Student Reading

Absorption is one of the ways in which light can interact with matter. In absorption, the energy of the light shining on an object (or a gas or liquid) is captured by the substance's molecules and used to move them from a ground (low energy) state to higher (excited) energy states.

Absorption by a Single Atom

Absorption can only occur when the energy packet carried by one photon of light is equal to the energy required to bring about transition between states. Since the energy of a photon is directly related to its frequency (by the formula E=hf where E is the photon's energy, f is its frequency, and h is Plancks' constant: 6.26 x 10^{-34} J s), then a given transition can only be caused by one specific frequency of light.

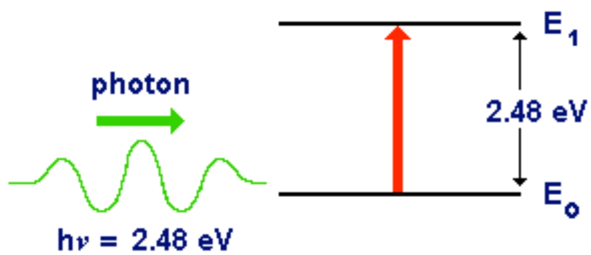
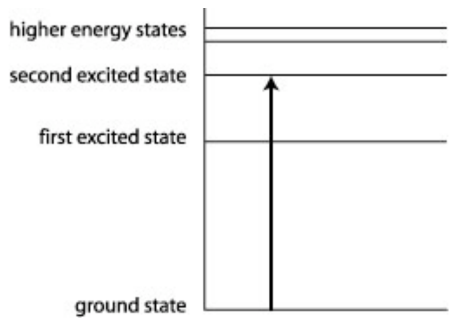


Figure 1: The energy of a photon must be exactly the same as the energy difference between levels for it to be absorbed [1]

The frequency of a photon is inversely related to its wavelength (by the formula λ=c/f where λ is the wavelength, f is the frequency and c is the speed of light in a vacuum). This means that the energy of the energy transition determines what frequency and hence what wavelength of light can be absorbed. The greater the energy of transition, the smaller the wavelength of light that can be absorbed.

What exactly are these different energy states that the atom can be in? Well, in atoms they correspond to the types of electron configurations in orbitals that are allowed by the rules of quantum mechanics. You may be familiar with transitions between electronic states if you've studied light emission by gasses. The main difference between the emission and the absorption of light is that in one case the light energy is being given off and in the other it is being captured, but in both cases the light energy of the photon absorbed or emitted corresponds to the energy difference between the two electronic states.

For example, Figure 2 shows several different energy levels and one possible transition for a hydrogen atom (in a gas). Each of the horizontal lines is an electronic state that the atom can be in and each the vertical line shows a possible "jump" or transition that could occur. Each possible transition (like the one shown) has a characteristic energy, and thus a specific wavelength of light that must be absorbed for it to occur. If we shine a flashlight at a sample of hydrogen atoms in a gas and measure the wavelengths of light that get through at the end, we would see an absorption spectrum like the one shown in the bottom of Figure 3. What you see is the full color spectrum, except for the "absorption lines", the specific wavelengths of light whose energy was absorbed because it corresponds to the energy difference between states for helium atoms. Similarly, if we stimulate a hydrogen atom to emit light, it will do so only at these same characteristic wavelengths whose energy (which is proportional to its frequency given by E=hf) corresponds to the energy between possible electron states for the hydrogen atom.



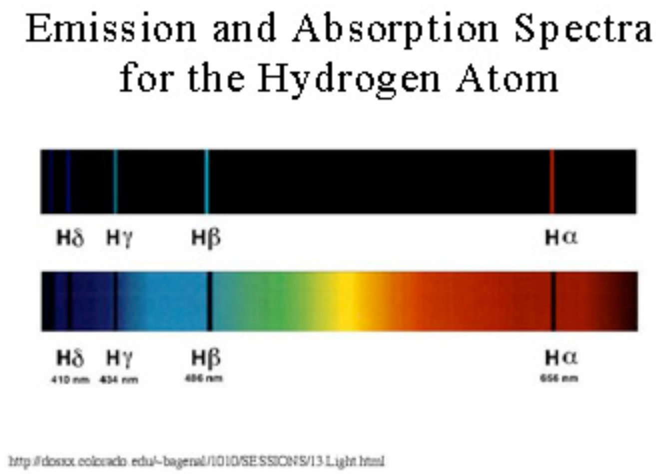
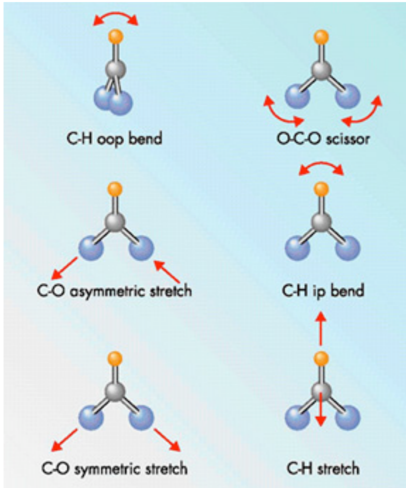


Figure 2: Energy states and one transition for the hydrogen atom	Figure 3: Emission (top) and absorption (bottom) spectra for the hydrogen atom [2] Each line corresponds to a single transition

Absorption by Molecules

When we start dealing with molecules instead of atoms, the situation gets more complicated. When we talk about atoms being bonded together, it is not as if they are solidly glued to one another. The "glue" that hold the atoms together in a molecule is the attractive forces between the electrons and the different nuclei (intramolecular forces.) As electrons are constantly in motion, the strength of these attractive forces fluctuates over time allowing the nuclei to move back and forth and giving rise to molecular vibrations. As with electronic states, there are only certain vibrational modes which are possible. One simple example of molecular vibration can be seen in formate ($COOH^-$), a molecular anion. The six possible vibration modes for formate are shown in Figure 4.

Within each vibrational state, there are also multiple ways that the atoms in the molecule can rotate. These are called rotational states and again there are a limited number of possible rotational states that the molecule can be in. When we consider vibrational and rotational states, we realize that even without exciting any electrons (ground state), there are a bunch of different energy states that a molecule can be in. Not surprisingly, this is also true for the excited state. So now we have a situation in which the molecule can transfer from any of the ground states to any of the excited states and instead of a single energy of transition, we have a large group of energy gaps able to absorb light energy.



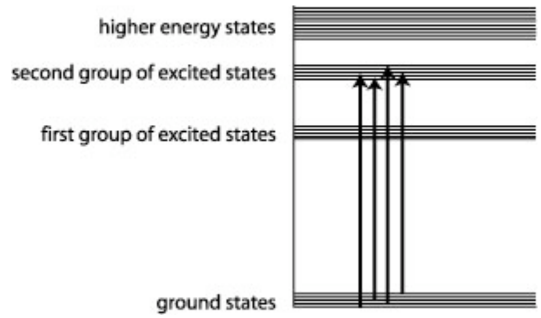


Figure 4: 6 Vibrational modes for formate ion (COOH ⁻) [3]

Figure 5: Multiple Transition Energies for Electrons in Molecules

The multiple energy transitions possible correspond to a range of photon energies and thus frequencies of light that can be absorbed. Comparing Figure 5 with Figure 2 we can see that where there was a single transition for an atom, there are multiple ones for a molecule. Each arrow corresponds to one transition. Since we now have clusters of energy levels (due to the different variations in rotational and vibrational energies possible), we have a cluster of multiple transitions with similar energies.

Thus light absorbing molecules produces multiple, closely spaced absorption lines which combine to form an absorption curve. Absorption curves can be described both by their absorption range and peak absorption wavelength as shown in Figure 6. Not that absorption is not uniform across the range; it is greatest at the peak and drops off rapidly. So absorption at the edges of the range is not very good.

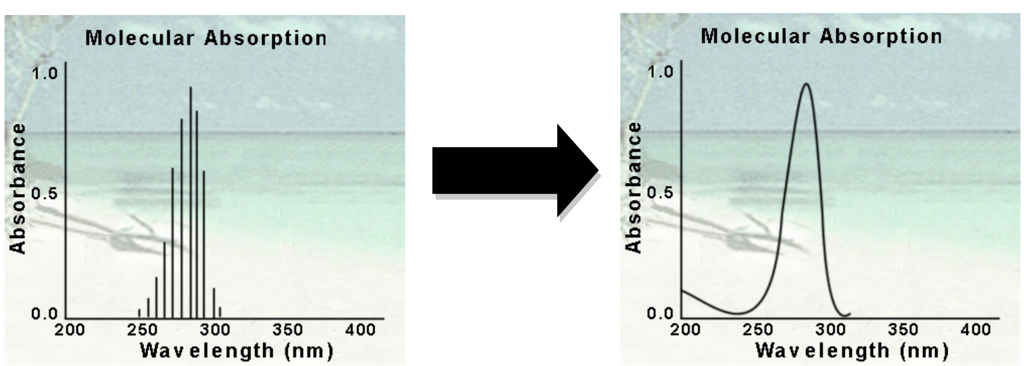
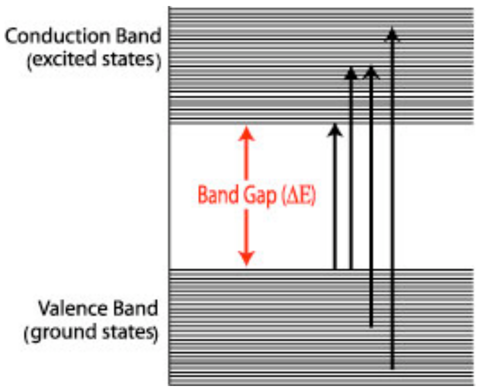


Figure 6: Absorption lines and curve spectrum for an organic molecule (Range = 245 – 305 nm) (Peak = 290 nm)

Absorption by Ionic Compounds

In inorganic compounds, there is no discrete atom or molecule to talk about. Instead the electrons belong to the positive nuclei as a collective group. Because so many atoms are close together and involved, there are a very large number of possible energy levels for electrons in both the ground and excited states as shown in Figure 7. Because there are so many possible energy states packed so closely together, we assume that electrons can have virtually any energy within each state and change between them very easily. Thus we call the group of possible energies for the ground states the "valence band" and the group of possible energies for the excited state the "conduction band".



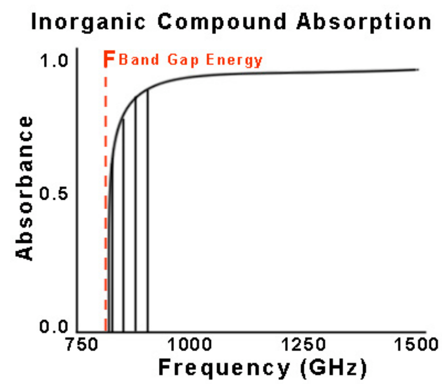


Figure 7: The large number of tightly packed energy levels possible for ground and excited electron states and possible transitions

Figure 8: Absorption versus frequency graph for an inorganic compound. The smallest f of light that can be absorbed corresponds has an energy equal to the band gap energy

Electrons can transition from any energy value in the valence band to any energy value in the conduction band. The energy spacing between the two bands is called the "band gap" and is the minimum amount of energy that the substance can absorb. This corresponds to the minimum frequency (and maximum wavelength) of light that the substance can absorb as shown in Figure 8. Now instead of seeing an absorption peak, we see almost complete absorption up to a cut-off wavelength (which corresponds to the energy of the band gap). For example, zinc oxide (ZnO) has a particular band gap (minimum energy that can be absorbed). Using $E=hf$ and $c=\lambda f$ (where h is Planck's constant and c is the speed of light) we can calculate that this corresponds to light with a wavelength of 380 nm. Thus light with higher frequencies and energies is almost completely absorbed and light with lower frequencies and energies is not absorbed. If we think about absorption in relation to the wavelength of light (instead of the frequency) our graph gets reversed (remember that wavelength and frequency are inversely related by $c=\lambda f$). This leads to an absorption spectra with the characteristic sharp drop shown in Figure 9. Thus the *minimum frequency* corresponds to a *maximum wavelength* up to which the inorganic sunscreen ingredients can absorb.

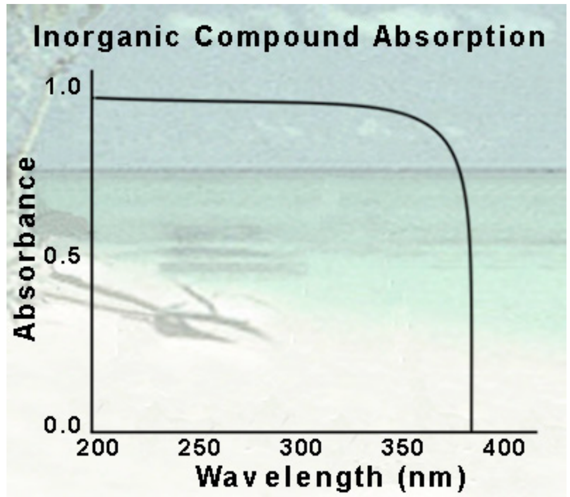


Figure 9: Absorption Spectrum for an Inorganic Compound (ZnO). Light with wavelengths less than 380 nm is almost completely absorbed. Light with wavelengths greater than 380 nm is not absorbed at all.

References

(Internet resources accessed December 2005)

[1] http://members.aol.com/WSRNet/tut/absorbu.htm

[2] http://staff.imsa.edu/science/astro/astrometry/spectra/sld010.htm

[3] http://www.isis.rl.ac.uk/ISIS97/feature14.htm

[4] http://www.nptel.iitm.ernet.in/courses/IITMadras/CY101/lecture16new/lecture16.htm

Absorption Summary: Student Handout

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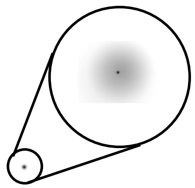
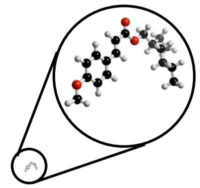
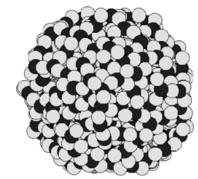
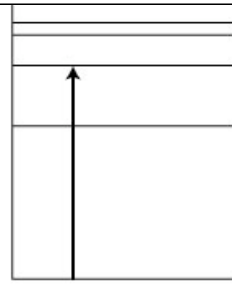
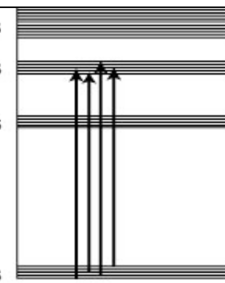
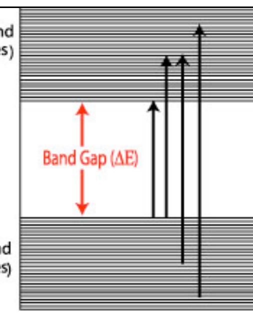
</td><td>Individual molecule
</td><td>Cluster of ions
</td></tr>
<tr><td>Energy Levels</td><td>
</td><td>
</td><td>
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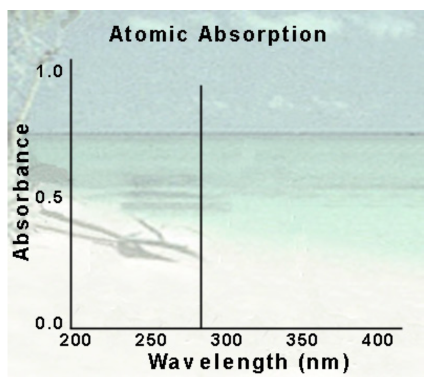
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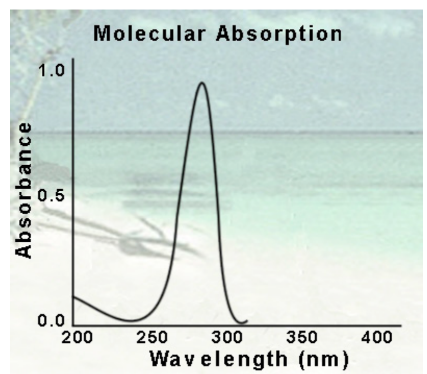
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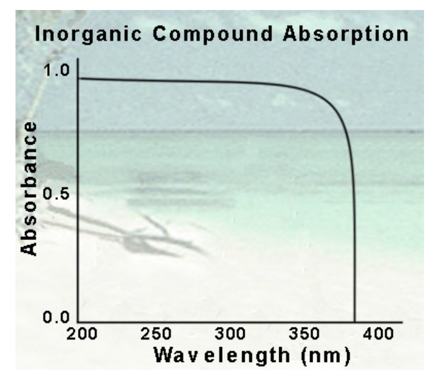
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<tr><td>UV Protection</td><td>Minimal</td><td>Parts of UVA or UVB spectrum</td><td>Broad spectrum UVA and UVB</td></tr>
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Name___________________________________ Date______________________ Period ______

Reflecting on the Guiding Questions: Student Worksheet

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

What I learned in this activity:
What I still want to know:

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

What I learned in this activity:
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:
What I still want to know:

Lesson 4:
How Sunscreens Appear:
Interactions with Visible Light

Teacher Materials

Contents

How Sunscreens Appear: Interactions with Visible Light: Teacher Lesson Plan

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 & Sunlight Animations Activity uses a pre-made flash animation (available from http://nanosense.org/activities/clearsunscreen/index.html) 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.

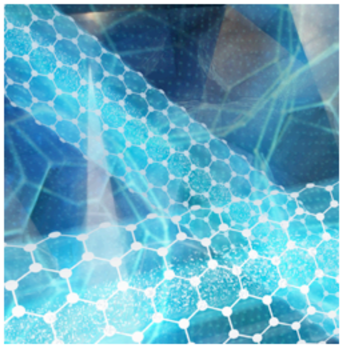
Sunscreen Appearance Timeline (with Ad Campaign Activity)

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.
	Hand out copies of the 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. Have students start to work in teams of 2 or 3 to create the animations. Circulate throughout the classroom to help students.	20 min	Photocopies of Ad Campaign Project (ChemSense Activity): Student Instructions Computer with ChemSense installed for each student team (2-3 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.	35min	
	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

Sunscreen Appearance Timeline (with Pre-made Animation Activity)

Day	Activity	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	
	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

NanoSense
the basic sense behind nanoscience

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

Source: http://www.4girls.gov/body/sunscreen.jpg

NanoSense 3

What makes sunscreens with traditional size inorganic clusters appear white?

And…

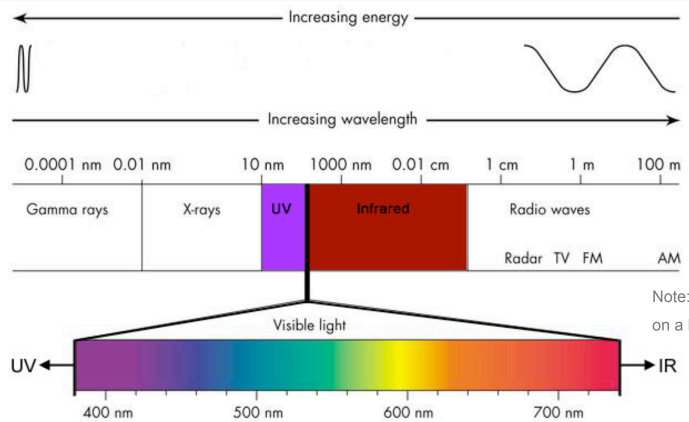
Source: http://www.loc.gov/rr/scitech/mysteries/images/sunscreen2.jpg

NanoSense 4

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

Source: Image adapted from http://www.loc.gov/rr/scitech/mysteries/images/sunscreen2.jpg

Remember the Electromagnetic Spectrum?



Note: Diagram drawn on a logarithmic scale

- **Different colors of light have different wavelengths and different energies**

Source: http://www.mhhe.com/physsci/astronomy/arny/instructor/graphics/ch03/0305.html

Reflected Light Gives an Object its Color

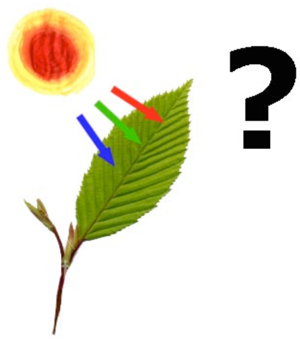
- **Visible light shining on an object is either absorbed or reflected**
  - Only reflected wavelengths reach our eyes
  - This makes object appear a certain color
- **Color is a function of the interaction between the light and the object**
  - It's not quite right to say an object *is* a certain color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

This leaf absorbs red and blue light but reflects green light

Source: Original Image

NanoSense 7

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

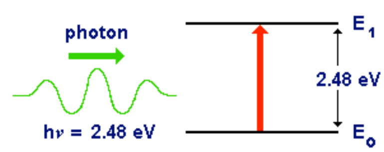


Source: Original Image

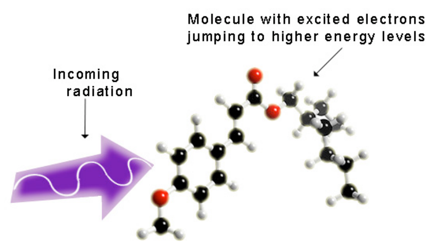
NanoSense 8

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

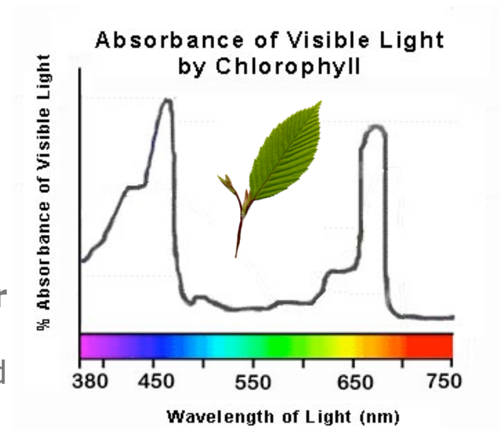


Source: Adapted from http://www.3dchem.com/molecules.asp?ID=135#and http://members.aol.com/WSRNet/tut/absorbu.htm

NanoSense 9

Chlorophyll's Visible Absorption Spectrum

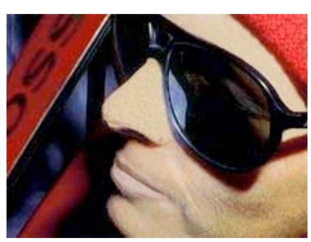
- **Chlorophyll is a molecule found in many plants**
  - It absorbs light to excite its electrons which are then used in photosynthesis
- **It absorbs most visible light <u>except</u> for green light**
  - This is why grass (and leaves and bushes) are green



Source: Graph adapted from http://www.botany.uwc.ac.za/ecotree/photosynthesis/spectrum.htm

NanoSense 10

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



Source: Image adapted from http://www.loc.gov/rr/scitech/mysteries/images/sunscreen2.jpg

NanoSense 11

Pigments in our Skin Give it "Color"

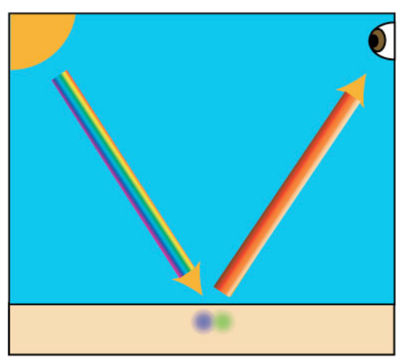
- **Pigment:**
  - Molecule that absorbs certain kinds of visible light and thus appears a certain color
- **Human skin color determined by melanin**
  - A group of pigment molecules
  - Each kind has a unique visible absorption spectrum
  - People can also have more or less of different kinds of melanin

Source: http://my.sunderland.ac.uk/web/support/equality/images/Faces%20Poster%20(img)

NanoSense 12

What Do Melanin Molecules Do?

- **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

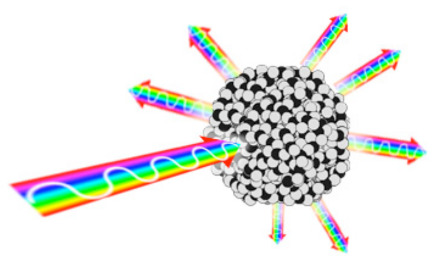


So what makes sunscreens with traditional inorganic clusters appear white?

Source: http://www.loc.gov/rr/scitech/mysteries/images/sunscreen2.jpg

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**

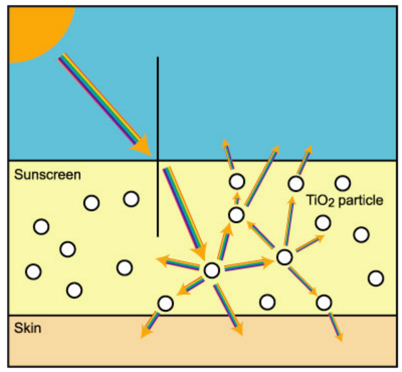


- **The energy from the light is redirected without a chemical interaction with the atoms**
  - This is different than absorption because no energy transformation occurs

Source: Original Image and http://www.geo.lsa.umich.edu/~crlb/COURSES/117/Lec23/lec23.html

Multiple Scattering

- After light is redirected once, it may encounter another cluster and be redirected again
- When this happens many times, it is called multiple scattering

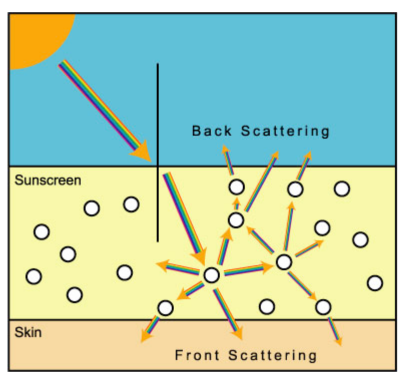


Source: Original Image

Front and Back Scattering

Light eventually goes in one of two directions:

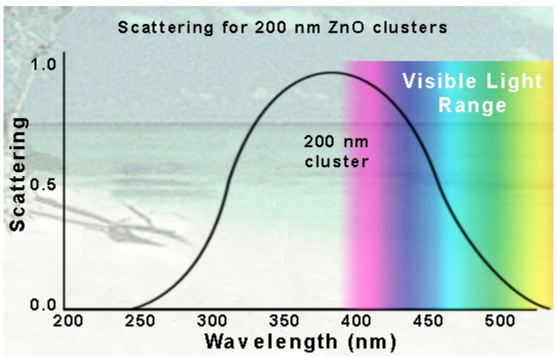
1. **Back the way it came (back scattering)**
   - Back-scattered light is reflected
2. **Forwards in the same general direction it was moving (front scattering)**
   - Front-scattered light is transmitted



Source: Original Image

Scattering by Traditional ZnO and TiO_2

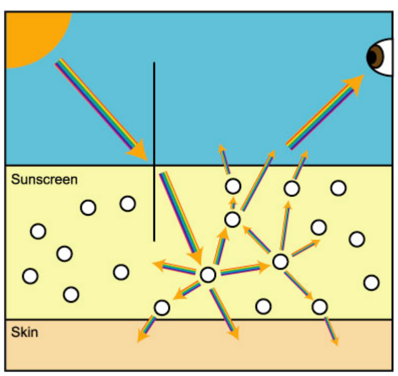
- **Maximum scattering occurs for wavelengths twice as large as the cluster**
  - Traditional ZnO and TiO_2 have a diameter > 200nm
  - Scatter light with a λ near 400 nm - this includes visible light!



Source: Original Image

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**



Source: Original Image

NanoSense 19

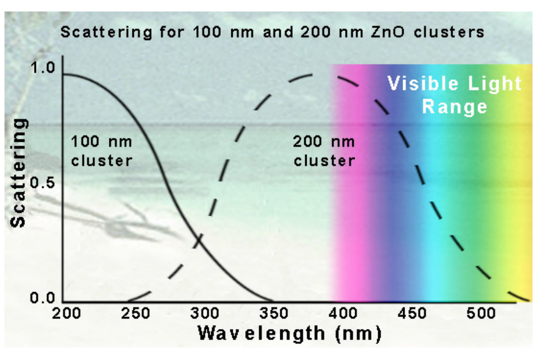
What do you think might be different about how nano sunscreen ingredients interact with visible light?

Source: Image adapted from http://www.loc.gov/rr/scitech/mysteries/images/sunscreen2.jpg

NanoSense 20

Nanosized Inorganic Clusters

- **Maximum scattering occurs for wavelengths twice as large as the clusters**
  - Make the clusters smaller (100 nm or less) and they won't scatter as much visible light

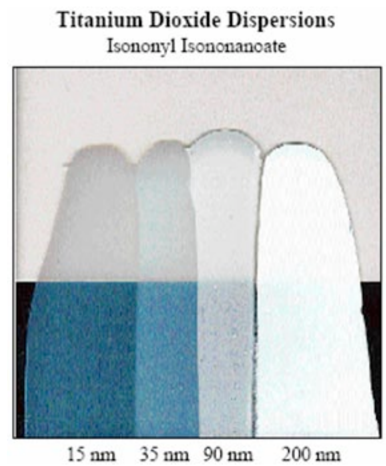


Source: Graph adapted from http://www.aims.gov.au/pages/research/projects/sunscreens/pages/sunscreens02.html

Nano ZnO and TiO_2

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

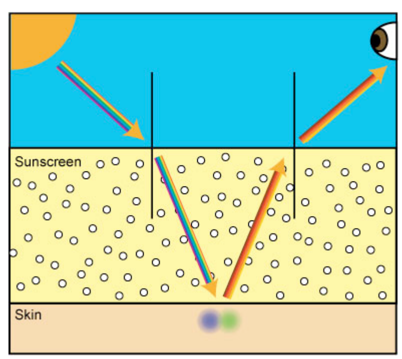
Transparencies of different sized TiO_2 clusters



Source: http://www.koboproductsinc.com/Downloads/Paper-Nice-David.pdf

"Clear" Sunscreen

- 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"



Source: Original Image

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

How Sunscreens Appear: Interactions with Visible Light: 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 & 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 (~400-500 nm). Red light has the least energy because it has the greatest wavelength (smallest frequency) of the visible spectrum (~700-750 nm). Yellow/Green light falls in the middle with a wavelength of ~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 ~$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 ~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 & 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.htmland are explained in the Sunscreens & Sunlight Animations: Teacher Instructions & 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 TiO2

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 & 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.

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 & 2 or 3 & 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.)

Rubric for Ad Campaign Evaluation – UV Light Animations

<table>
<tr><th colspan="2">Category</th><th>Novice
(1)
Absent, missing or confused</th><th>Apprentice
(2)
Partially developed</th><th>Skilled
(3)
Adequately developed</th><th>Masterful
(4)
Fully developed</th></tr>
<tr><td colspan="2" rowspan="2">Required Elements
• Light source
• Skin surface
• Sunscreen lotion
• Suspended ZnO particles
• 2 + UVA rays
• 2 + UVB rays
• 10 + frames</td><td>0 - 2 of the required elements are present.</td><td>3 - 4 of the required elements are present.</td><td>5 – 6 of the required elements are present.</td><td>All 7 required elements are present.</td></tr>
<tr><td>Few of the required elements are accurately depicted.</td><td>Some of the required elements are accurately depicted.</td><td>Most of the required elements are accurately depicted.</td><td>All of the required elements are accurately depicted.</td></tr>
<tr><td colspan="2">Interactions of light rays with ZnO particles (and skin when appropriate) correctly shown</td><td rowspan="2">Few or no key aspects of the interaction are correctly shown.</td><td rowspan="2">Some aspects of the interaction are correctly shown.</td><td rowspan="2">Most key aspects of the interaction are correctly shown.</td><td rowspan="2">All key aspects of the interaction are correctly shown.</td></tr>
<tr><td>50 nm:
• All light is only absorbed
• UVA / UVB interact the same</td><td>300 nm:
• Light is both absorbed and scattered
• UVA / UVB interact the same</td></tr>
<tr><td colspan="2">All relevant blocking mechanisms correctly shown</td><td rowspan="2">Few or no key aspects of the blocking mechanism are correctly shown.</td><td rowspan="2">Some key aspects of the blocking mechanism are correctly shown.</td><td rowspan="2">Most key aspects of the blocking mechanism are correctly shown.</td><td rowspan="2">All key aspects of the blocking mechanism are correctly shown.</td></tr>
<tr><td>50 and 300 nm:
• Absorption shows light energy being captured by ZnO particles</td><td>300 nm only:
• Scattering shows light being redirected in multiple directions</td></tr>
<tr><td colspan="2" rowspan="2">Teamwork
• All team members contributed significantly to the project
• Group worked together to manage problems as a team</td><td>Few team members contributed to the project.</td><td>Some team members contributed to the project.</td><td>Most team members contributed to the project.</td><td>All team members contributed to the project.</td></tr>
<tr><td>Group did not address the problems encountered.</td><td>Group did not manage problems effectively.</td><td>Problems in the group managed by one or two individuals.</td><td>Group worked together to solve problems.</td></tr>
</table>

Rubric for Ad Campaign Evaluation – Visible Light Animations

<table>
<tr><th colspan="2">Category</th><th>Novice
(1)
Absent, missing or confused</th><th>Apprentice
(2)
Partially developed</th><th>Skilled
(3)
Adequately developed</th><th>Masterful
(4)
Fully developed</th></tr>
<tr><td colspan="2" rowspan="2">Required Elements
• Light source
• Human observer
• Skin surface
• Sunscreen lotion
• Suspended ZnO particles
• 5 + visible light rays
• 10 + frames</td><td>0 - 2 of the required elements are present.</td><td>3 - 4 of the required elements are present.</td><td>5 – 6 of the required elements are present.</td><td>All 7 required elements are present.</td></tr>
<tr><td>Few of the required elements are accurately depicted.</td><td>Some of the required elements are accurately depicted.</td><td>Most of the required elements are accurately depicted.</td><td>All of the required elements are accurately depicted.</td></tr>
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<tr><td>50 nm:
• No scattering
• Blue/green light absorbed by skin</td><td>• Few or no key aspects of the observer's view are correctly shown.</td></tr>
<tr><td colspan="2">What the observer sees and why they see is correctly shown</td><td rowspan="2">Few or no key aspects of the observer's view are correctly shown.</td><td rowspan="2">Some key aspects of the observer's view are correctly shown.</td><td rowspan="2">Most key aspects of the observer's view are correctly shown.</td><td rowspan="2">All key aspects of the observer's view are correctly shown.</td></tr>
<tr><td>50 nm:
• Skin
• Peach/Brown color</td><td>300 nm:
• Sunscreen
• White color</td></tr>
<tr><td colspan="2" rowspan="2">Teamwork
• All team members contributed significantly to the project
• Group worked together to manage problems as a team</td><td>Few team members contributed to the project.</td><td>Some team members contributed to the project.</td><td>Most team members contributed to the project.</td><td>All team members contributed to the project.</td></tr>
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</table>

Sunscreens & Sunlight Animations: Teacher Instructions & 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/clearsunscreen/sunscreenanimation.html

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 (~400-550 nm) wavelengths of light are absorbed by pigments in the skin, while the red-orange-yellow (~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 (~400-550 nm) wavelengths of light are absorbed by pigments in the skin, while the red-orange-yellow (~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 (~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 semi-transparent (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 & Answer Key (Lesson 4)

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 380nm (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 > 200nm), they don’t scatter visible light (maximum scattering occurs at $\lambda = 2 * \text{diameter}$) and thus appear clear on our skin.

What I still want to know:

Lesson 4: How Sunscreens Appear: Interactions with Visible Light

Student Materials

Contents

Scattering of Light by Suspended Clusters: Student Reading

Figure 1a: Dust clusters from a passing car scatter sunlight

Figure 1b: Without the dust clusters we can not see the sun rays

What is Scattering?

Scattering is a phenomenon in which light is redirected in different directions by small clusters of atoms suspended in some other substance. A common example of scattering is when you shake out a dusty object in a sunny room - the dust seems to sparkle in the air. This effect occurs because the dust is scattering the sunlight, which then reaches your eyes. Scattering also explains why snow and salt are white, and why the sky is blue. In each of these situations, the light is being redirected many times before it reaches our eyes. This is why the process is called multiple scattering.

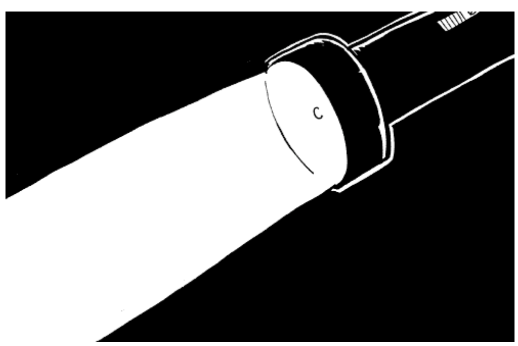


Figure 2: What is wrong with this picture?[1]

In many cartoons we often see the "light" from a flashlight in the dark, but this is a false image because we can not see this light unless there are clusters there to scatter it towards our eyes. Try shining a flashlight at a wall in a dark room. Can you see the beam of light between the wall and the flashlight (like in the picture above)? Now sprinkle some baby powder in the air while you shine the beam. Can you see the beam now?

How Does Scattering Occur?

When lots of clusters of one material are suspended in another material (for example drops of water in the air, or active sunscreen ingredients in the lotion) light has a chance to interact with these many clusters. The interaction bends the light in many different directions. After this, it will then continue traveling in the suspension medium until it reaches another cluster. If the light is bent multiple times in multiple directions, we call this multiple scattering.

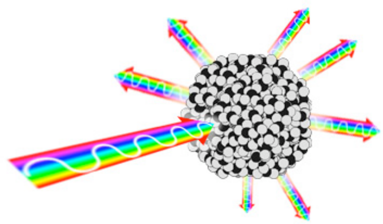


Figure 3: Scattering of light by a suspended cluster

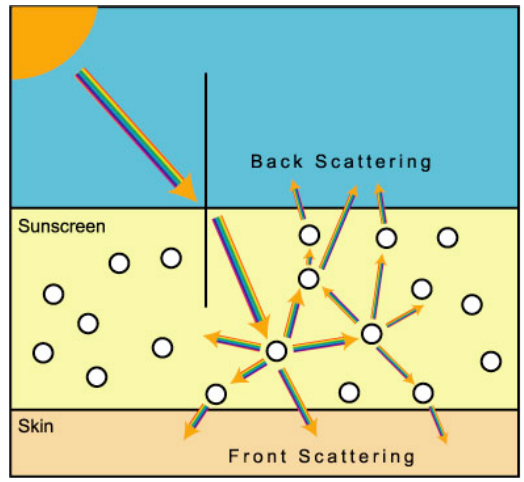


Figure 4: Multiple scattering of light by suspended cluster

While on the micro-level scattering redirects the light in many different directions, on the macro-level this combines to produce one of two results: the light is sent back in the general direction from which it came at various angles (back scattering) or the light continues in the same general direction it was moving, but at various angles (front scattering).

Does Scattering Always Happen?

Whether or not scattering will occur depends on many factors. For clusters suspended in a medium some of the most important factors are: the identity of the clusters, the identity of the suspending medium and the cluster size. Scattering happens most when the clusters have a diameter that is half as big as the wavelength of light involved. So a 200 nm cluster would scatter 400 nm light the most and it would scatter 300-500 nm light quite a bit as well. The amount of scattering continues to decrease as wavelengths become much bigger or much smaller than 400 nm, as shown in figure 5.

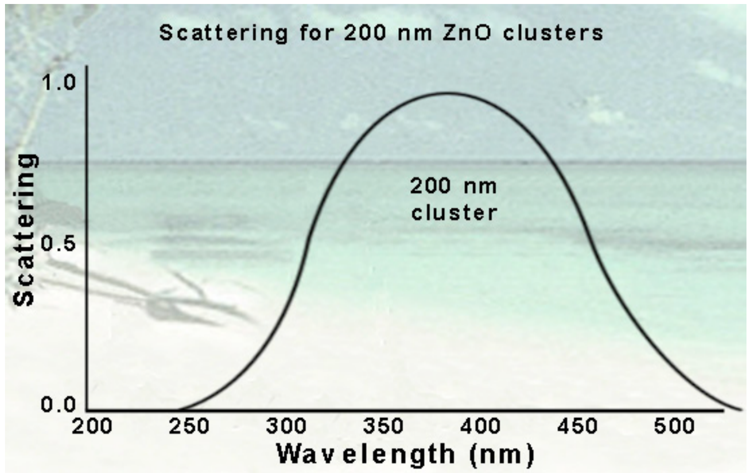


Figure 5: Graph of Scattering for a 200 nm ZnO Cluster in Sunscreen

References

(Accessed December 2005)

[1] http://www.liberty-news.com/showCartoons.php?artist=Lalo+Alcaraz&src=h2856

Ad Campaign Project: Student Instructions

Overview

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.

Animation Matrix

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

Requirements

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

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.)

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.
	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 where appropriate) 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.
All relevant blocking mechanisms correctly shown	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.
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.

Rubric for Ad Campaign Evaluation – Visible Light Animations

<table>
<tr><th>Category</th><th>Novice
(1)
Absent, missing or confused</th><th>Apprentice
(2)
Partially developed</th><th>Skilled
(3)
Adequately developed</th><th>Masterful
(4)
Fully developed</th></tr>
<tr><td rowspan="2">Required Elements
• Light source
• Human observer
• Skin surface
• Sunscreen lotion
• Suspended ZnO particles
• 5 + visible light rays
• 10 + frames</td><td>0 - 2 of the required elements are present.</td><td>3 - 4 of the required elements are present.</td><td>5 – 6 of the required elements are present.</td><td>All 7 required elements are present.</td></tr>
<tr><td>Few of the required elements are accurately depicted.</td><td>Some of the required elements are accurately depicted.</td><td>Most of the required elements are accurately depicted.</td><td>All of the required elements are accurately depicted.</td></tr>
<tr><td>Interactions of light rays with ZnO particles (and skin when appropriate) correctly shown</td><td>Few or no key aspects of the interaction are correctly shown.</td><td>Some aspects of the interaction are correctly shown.</td><td>Most key aspects of the interaction are correctly shown.</td><td>All key aspects of the interaction are correctly shown.</td></tr>
<tr><td>What the observer sees and why they see is correctly shown</td><td>Few or no key aspects of the observer's view are correctly shown.</td><td>Some key aspects of the observer's view are correctly shown.</td><td>Most key aspects of the observer's view are correctly shown.</td><td>All key aspects of the observer's view are correctly shown.</td></tr>
<tr><td rowspan="2">Teamwork
• All team members contributed significantly to the project
• Group worked together to manage problems as a team</td><td>Few team members contributed to the project.</td><td>Some team members contributed to the project.</td><td>Most team members contributed to the project.</td><td>All team members contributed to the project.</td></tr>
<tr><td>Group did not address the problems encountered.</td><td>Group did not manage problems effectively.</td><td>Problems in the group managed by one or two individuals.</td><td>Group worked together to solve problems.</td></tr>
</table>

Name_________________________________ Date_____________________ Period ______

Sunscreens & Sunlight Animations: Student Instructions & Worksheet

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 ate 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.

Questions

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

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?

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

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

    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.

    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

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
   b. Skin with 200 nm ZnO particles sunscreen
   c. Skin with 30 nm ZnO particle sunscreen
4. What determines what the observer sees? (Do they see the skin or the sunscreen? What color do they see?)

5. How does scattering affect what the observer sees?

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

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

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?

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

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?

b. What are some other ways these animations have simplified the model of the real world situation they describe?

c. What are some of the benefits of making a simplified model? What are some of the drawbacks?

Name_________________________________ Date_____________________ Period ______

Reflecting on the Guiding Questions: Student Worksheet

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

What I learned in this activity:
What I still want to know:

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

What I learned in this activity:
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:
What I still want to know:

Lesson 5: Culminating Activities

Teacher Materials

Contents

Culminating Activities: Teacher Lesson Plan

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.

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.
	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

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
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 & 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 x 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

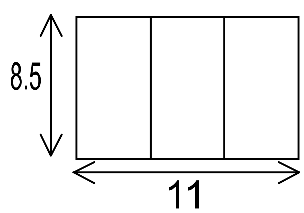
It is up to you how "professional" you want your students to make their pamphlets. If you have two class periods or less to devote to this project, we suggest that you have your students focus on the content and produce "draft versions" of the pamphlet.

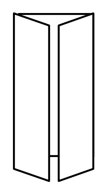
By Hand:

Take a regular piece of 8.5 x 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>Page Setup to choose a Landscape Orientation and make all of the margins 0.5 inches. Go to Format>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.





Folded Pamphlet

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.

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.
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.
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

30 points total

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.

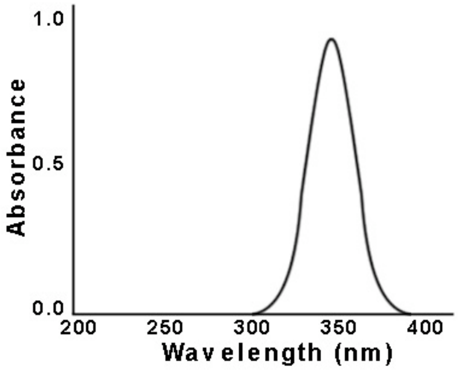
4. How do you know if a sunscreen protects against UVA light (now and future)? *(2 points)*

- 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 point)*

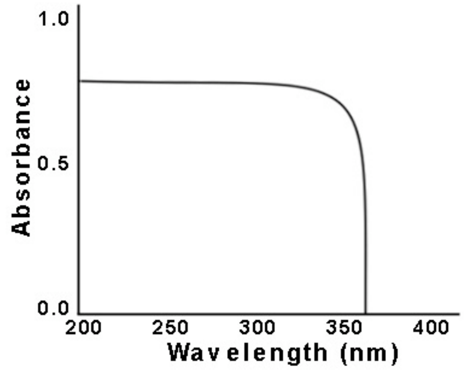
- A sunscreen's SPF (Sunburn Protection Factor) number indicates its ability to absorb UVB light (a higher number equals greater UVB protection).

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)*



a) $\boxed{\textbf{UVA}}$ **UVB**

b) $\boxed{\textbf{Organic}}$ **Inorganic**



a) $\boxed{\textbf{UVA}}$ $\boxed{\textbf{UVB}}$

b) **Organic** $\boxed{\textbf{Inorganic}}$

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 TiO2 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)*

	Organic Ingredients (e.g. PABA)	Inorganic Ingredients (e.g. Classic Zinc Oxide used by lifeguards)
Chemical Structure	Similar or $\boxed{\text{Different}}$ How: Nano ingredients are small ionic clusters while organic ingredients are molecules.	$\boxed{\text{Similar}}$ 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 $\boxed{\text{Different}}$ How: Organic ingredients each block a small part of the UV spectrum (generally UVB) while nano ingredients block almost the whole thing,	$\boxed{\text{Similar}}$ or Different How: Both nano ingredients and traditional inorganic ingredients block almost the whole UV spectrum.
Way Light is Blocked	$\boxed{\text{Similar}}$ 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)	$\boxed{\text{Similar}}$ or Different How: Both nano and inorganic ingredients block UV light via absorption.
Appearance on the Skin	$\boxed{\text{Similar}}$ or Different How: Both nano and organic ingredients appear clear on the skin.	Similar or $\boxed{\text{Different}}$ How: Traditional inorganic ingredients appear white on the skin while nano ingredients appear clear.

Clear Sunscreen Final Reflections: Teacher Instructions & 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.

1. What are the most important factors to consider in choosing a sunscreen?	**How sure are you that this is true?** Not So Sure	Kind-of Sure	Very Sure
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.			
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.			

2. How do you know if a sunscreen has “nano” ingredients?	**How sure are you that this is true?** Not So Sure	Kind-of Sure	Very Sure
“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.			
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 $\lambda = 2 * \text{diameter}$).			
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.			

3. How do “nano” sunscreen ingredients differ from most other ingredients currently used in sunscreens?	**How sure are you that this is true?** Not So Sure	Kind-of Sure	Very Sure
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) – 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: 380nm (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 > 200nm), they don’t scatter visible light (maximum scattering occurs at $\lambda = 2 * \text{diameter}$) and thus appear clear on our skin.			

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 √ 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?

Lesson 5: Culminating Activities

Student Materials

Contents

Consumer Choice Project: Student Instructions

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 x 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.
- A list of common nanoparticulate active sunscreen ingredients and how to know if your sunscreen contains them.
- 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).
- An explanation of why nanoparticulate sunscreen ingredients are clear and a diagram that illustrates the science principles involved.
- A transmission versus wavelength graph that supports this explanation.
- An explanation of the possible downsides / dangers of using sunscreens with nanoparticulate ingredients.
- 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.

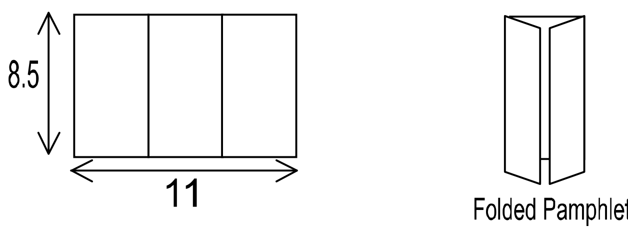
How to Make a Pamphlet

By Hand:

Take a regular piece of 8.5 x 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>Page Setup to choose a Landscape Orientation and make all of the margins 0.5 inches. Go to Format>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

Name________________________________ Date_____________________ Period ______

Consumer Choice Project: Peer Feedback Form

1. What are the name(s) of the student team who developed the pamphlet you are evaluating?

2. Is all of the required information present and correct?

	Not at all				Completely
Overview of nanoparticulate sunscreen ingredients and similarities/differences from other active ingredients.	1	2	3	4	5
List of common nanoparticulate active sunscreen ingredients and how to know if your sunscreen contains them.	1	2	3	4	5
Explanation of how nanoparticulate sunscreens block UV light from reaching the skin and benefits of using them.	1	2	3	4	5
Scientific explanation and diagram of why nanoparticulate sunscreen ingredients are clear.	1	2	3	4	5
Transmission versus wavelength graph that supports the explanation.	1	2	3	4	5
Explanation of possible downsides / dangers of using sunscreens with nanoparticulate ingredients.	1	2	3	4	5
SmartShopper's position on the use of sunscreens nanoparticulate ingredients with justification.	1	2	3	4	5

3. List any information that you think is missing or incorrect here:

4. Was the information in the pamphlet presented clearly and communicated in an appropriate way?

Not at all	A little	Somewhat	A lot	Completely
1	2	3	4	5

5. If not, please identify the area(s) of confusion here:

6. To what degree are scientific explanations used to back up pamphlets claims?

Not at all	A little	Somewhat	A lot	Completely
1	2	3	4	5

7. To what degree do the diagram and graph enhance the explanation of why nanoparticulate sunscreen ingredients are clear?

Not at all	A little	Somewhat	A lot	Completely
1	2	3	4	5

8. To what degree is a convincing argument made—one that weighs all of the relevant information for the position taken on nanoparticulate sunscreen use?

Not at all	A little	Somewhat	A lot	Completely
1	2	3	4	5

9. Describe one thing that you think the pamphlet did very well:

10. Give at least one suggestion for improving the pamphlet:

Name_________________________________ Date_____________________ Period ______

The Science Behind the Sunscreen: Student Quiz

30 points total

1. Why is UV light a source of health concern when visible and infrared light are not? *(2 points)*

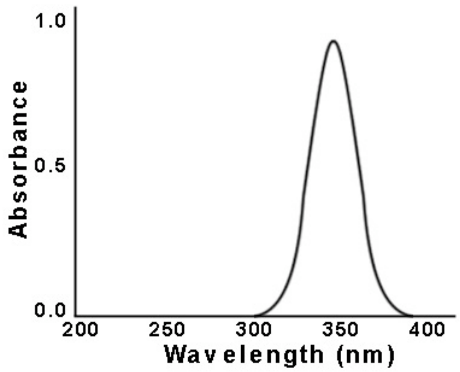
2. List 2 kinds of damage to the body caused by UV radiation. *(2 points)*

3. Explain in your own words why it is important to block UVA light. *(2 points)*

4. How do you know if a sunscreen protects against UVA light (now and future)? *(2 points)*

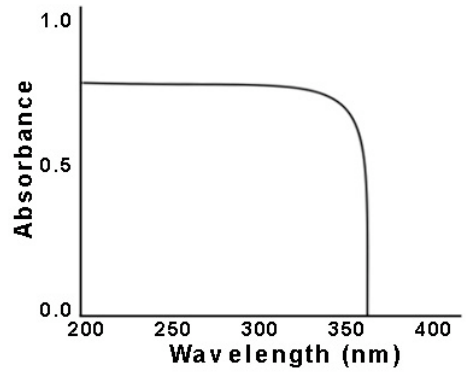
5. How do you know if a sunscreen protects against UVB light? *(1 point)*

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)*



a) UVA UVB

b) **Organic Inorganic**



a) UVA UVB

b) **Organic Inorganic**

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)*

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

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

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)*

	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: Student Worksheet

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.

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

Contents

One-Day Version of Clear Sunscreen: Teacher Lesson Plan

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/clearsunscreen/index.html.
- 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)

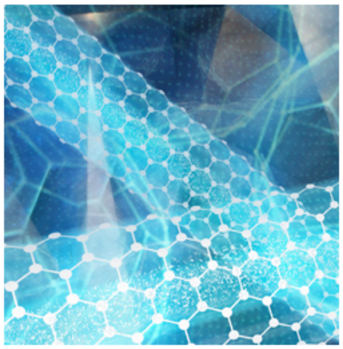
Students will be able to:

(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.

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/clearsunscreen/index.html Copies of Student Handouts



NanoSunscreen

The Wave of the Future?

NanoSense
the basic sense behind nanoscience

Part 1
Understanding the Danger

Why use sunscreen?

Too Much Sun Exposure is Bad for Your Body

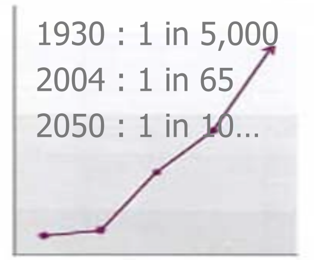
- Premature skin aging (wrinkles)
- Sunburns
- Skin cancer
- Cataracts

Sources: http://www.oasishospital.org/previousnews.html; http://wohba.com/archive/2005_03_01_archive.html

Skin Cancer Rates are Rising Fast

Skin cancer:
- ~50% of all cancer cases
- > 1 million cases each year
- ~ 1 person dies every hour

Probability of getting skin cancer



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

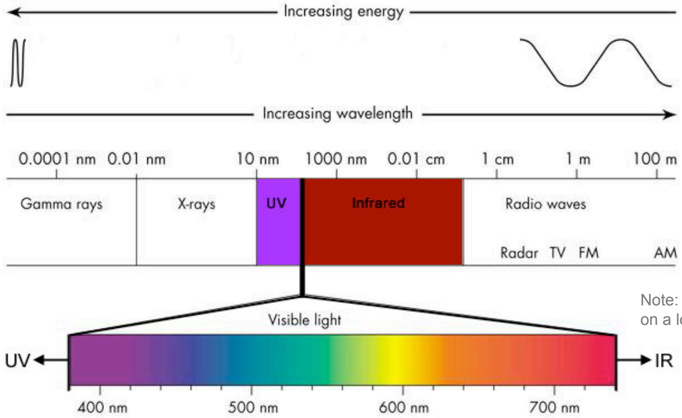
Sources: http://www.msnbc.msn.com/id/8379291/site/newsweek/ ; http://www.skincarephysicians.com/skincancernet/whatis.html; http://www.msu.edu/~aslocum/sun/skincancer.htm

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

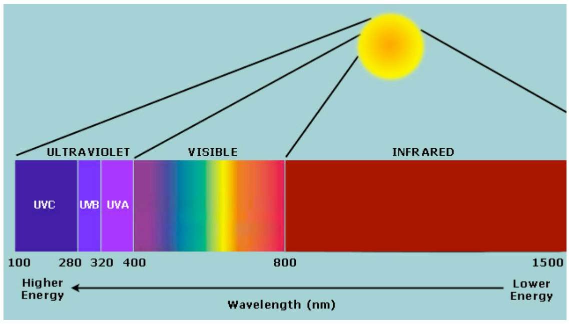


Note: Diagram drawn on a logarithmic scale

Source: Adapted from http://www.mhhe.com/physsci/astronomy/arny/instructor/graphics/ch03/0305.html

The Sun's Radiation Spectrum I

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

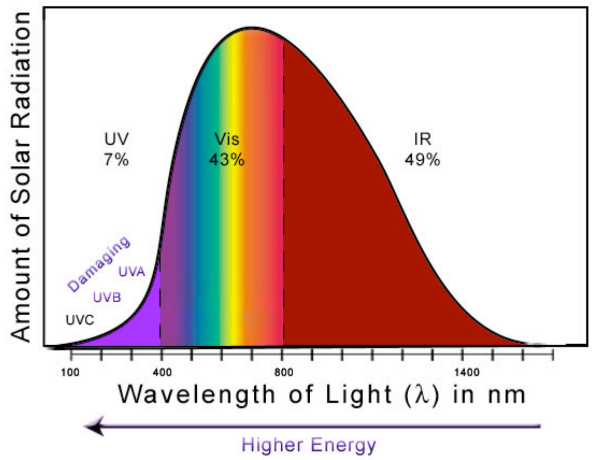


- **Higher energy radiation can damage our skin**

Source: http://www.arpansa.gov.au/is_sunys.htm

The Sun's Radiation Spectrum II

- **How much UV, Vis & IR does the sun emit?**



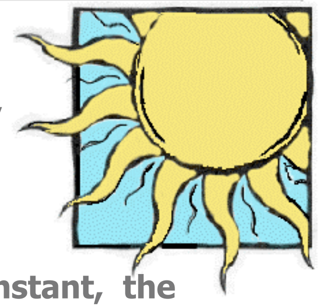
Source: http://www.arpansa.gov.au/is_sunys.htm

How can the sun's rays harm us?

NanoSense 11

Sun Rays are Radiation

- **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**

Source: http://www.pueblo.gsa.gov/cic_text/health/sun_uv/sun-uv-you.htm

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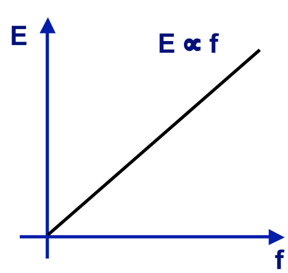
Radiation Energy I

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

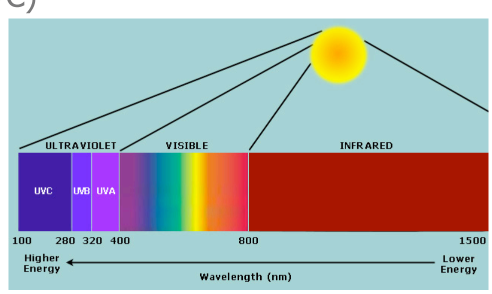
- This relates not only to how much energy is in each packet but also to the total number of packets arriving at a given location (such as our skin)

- 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

Source: http://www.epa.gov/sunwise/uvwhat.html

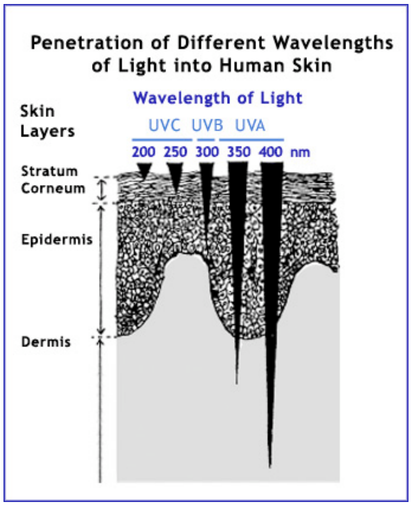
Skin Damage I

- **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**



Source: http://www.arpansa.gov.au/is_sunys.htm

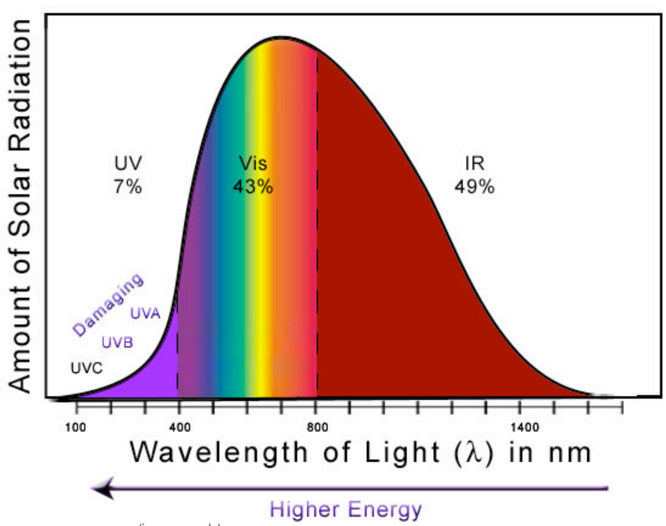
Skin Damage II



- 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

Source: 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.

Sun Radiation Summary I



Source: http://www.arpansa.gov.au/is_sunys.htm

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?
UVC	~200-290 nm (Short-wave UV)	Increasing Energy 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
Vis	~400-800 nm	Lower Energy	~43 %	None Currently Known	Yes
IR	~800-120,000 nm Increasing Wavelength	Lowest Energy	~49%	Heat Sensation (high λ IR)	No

Part 2
Protecting Ourselves

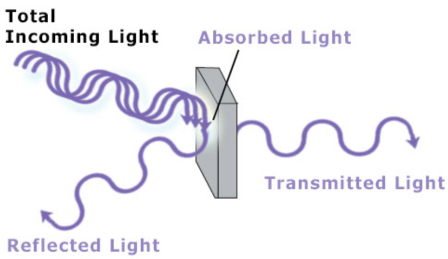
What do Sunscreens Do?

- Sunscreens are designed to protect us by preventing UV rays from reaching our skin
- But what does it mean to **"block"** UV rays?

Source: Image adapted from http://www.ashevilleparc.org/files/sssd1small.jpg

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



Transmission
Reflection
+ Absorption
100%

- If we say that light is "blocked" it means that it is either absorbed or reflected by the material
  - Sunscreens mainly block via absorption

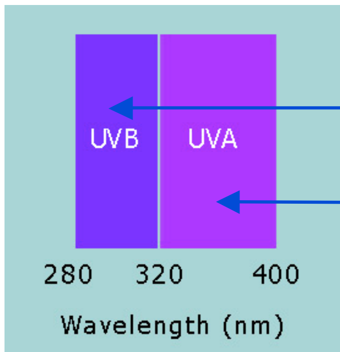
Source: Original Image

NanoSense

A Brief History of Sunscreens: The Beginning

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

WWII soldiers in the sun



The sunburn causing rays were labeled as UV-B

Longer wavelengths in the UV range were called UV-A

Sources: http://www.bbc.co.uk/wiltshire/content/articles/2005/05/05/peoples_war_feature.shtml
http://www.arpansa.gov.au/is_sunys.htm

NanoSense

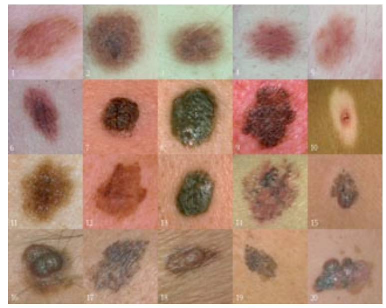
A Brief History of Sunscreens: The SPF Rating

- **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

Sources: http://www.shop.beautysurg.com/ProductImages/skincare/14521.jpg and http://www.shop.beautysurg.com/ProductImages/skincare/14520.jpg

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**



Twenty different skin cancer lesions

- ***NEW:* The FDA has just proposed a 4-star UVA rating to be included on sunscreen labels!**

Low ★★★★ Med ★★★★ High ★★★★ Highest ★★★★

Source: http://www.cs.wright.edu/~agoshtas/fig8.jpg

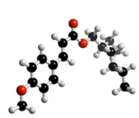
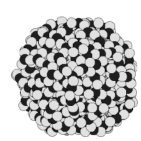
How do you know if your sunscreen is a good UVA blocker?

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

Source: Original Image

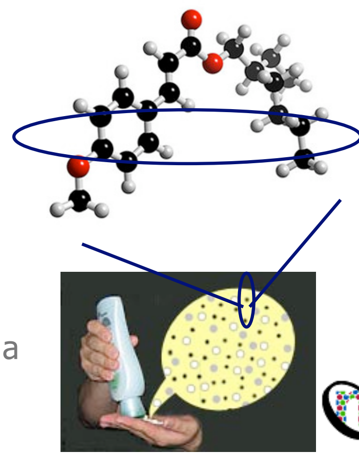
Sunscreen Ingredients Overview

	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 & 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)

Octyl methoxycinnamate ($C_{18}H_{26}O_3$)
an organic sunscreen ingredient

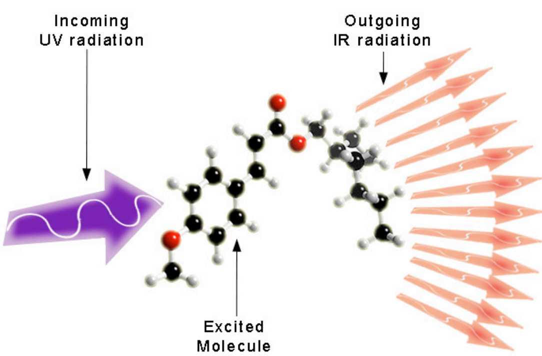


Sources: http://www.3dchem.com/molecules.asp?ID=135# and original image

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



Source: Adapted from http://www.3dchem.com/molecules.asp?ID=135#and http://members.aol.com/WSRNet/tut/absorbu.htm

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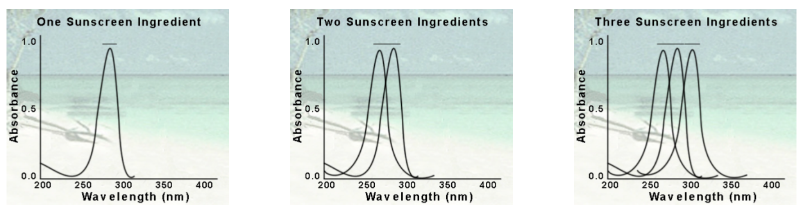
Organic Ingredients: Absorption Range

- **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



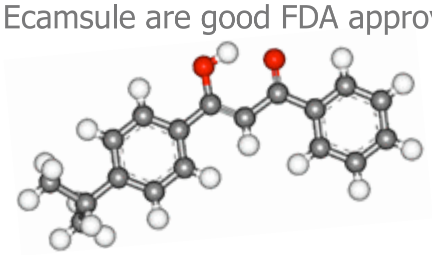
Source: Graphs adapted from http://www.aims.gov.au/pages/research/projects/sunscreens/pages/sunscreens02.html

NanoSense 30

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

Avobezone molecule



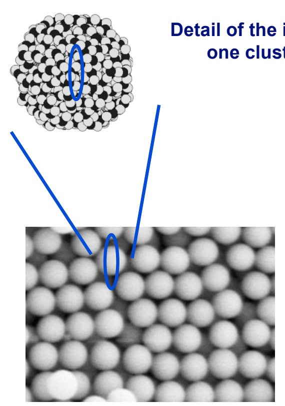
Source: http://jchemed.chem.wisc.edu/JCEWWW/Features/MonthlyMolecules/2004/Oct/JCE2004p1491fig4.gif

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**
  - Ionic attraction
  - Cluster of ions
  - Formula unit doesn't dictate size
- **Size**
  - Varies with # of ions in cluster
  - Typically ~10 nm – 300 nm



Detail of the ions in one cluster

Group of TiO_2 particles

Source: http://www.microspheres-nanospheres.com/Images/Titania/TIO2%20P7.jpg and image adapted from http://www.cse.clrc.ac.uk/msi/projects/ropa.shtml

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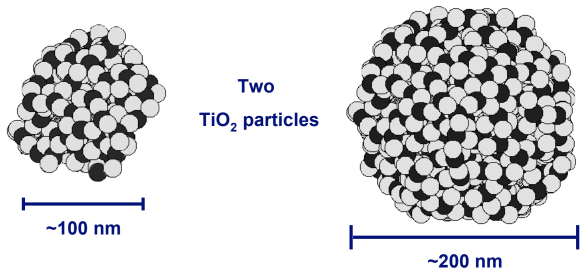
Inorganic Ingredients: Cluster Size

- **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



Source: Images adapted from http://www.cse.clrc.ac.uk/msi/projects/ropa.shtml

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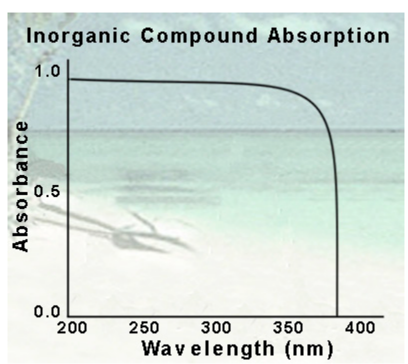
Inorganic Ingredients: UV Blocking

- **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 ~380nm
  - How is the absorption pattern different than for organics?



Source: Graph adapted from http://www.aims.gov.au/pages/research/projects/sunscreens/pages/sunscreens02.html

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

Source: http://www.loc.gov/rr/scitech/mysteries/images/sunscreen2.jpg

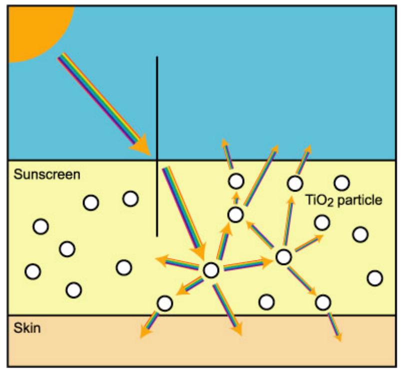
Appearance Matters

- 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

Source: http://www.4girls.gov/body/sunscreen.jpg

Why Do They Appear White? I

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

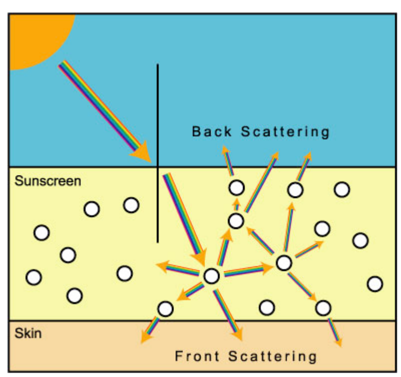


Source: Original Image

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



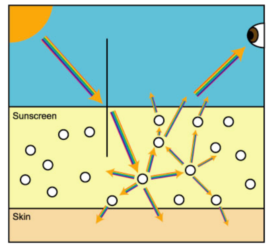
Source: Original Image

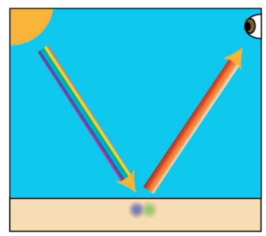
NanoSense 39

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





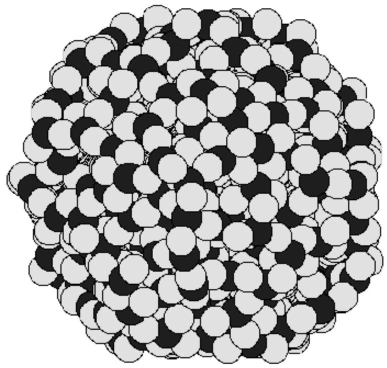
Source: Original Image

NanoSense 40

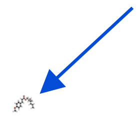
Why don’t organic sunscreen ingredients scatter visible light?

Source: Adapted from http://www.loc.gov/rr/scitech/mysteries/images/sunscreen2.jpg

Organic Sunscreen Molecules are Too Small to Scatter Visible Light



200 nm TiO_2 particle
(Inorganic)



Methoxycinnamate (<10 nm)
(Organic)

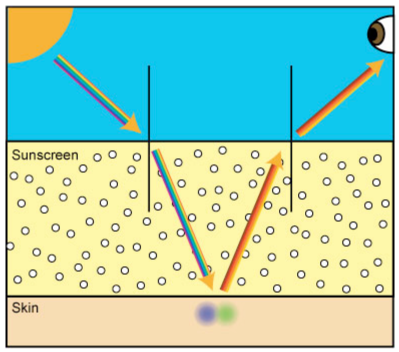
Source: Images adapted from http://www.cse.clrc.ac.uk/msi/projects/ropa.shtml and http://www.3dchem.com/molecules.asp?ID=135#

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

Source: Adapted from http://www.loc.gov/rr/scitech/mysteries/images/sunscreen2.jpg

Nanosized Inorganic Clusters I

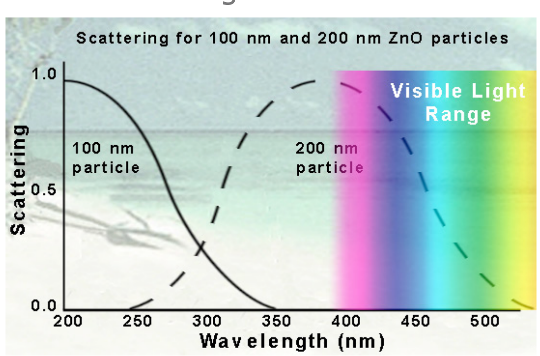
- **Maximum scattering occurs for wavelengths twice as large as the clusters**
  - Make the clusters smaller (100 nm or less) and they won't scatter visible light



Source: Graph adapted from http://www.aims.gov.au/pages/research/projects/sunscreens/pages/sunscreens02.html

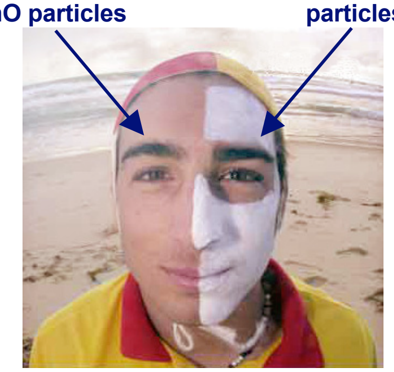
Nanosized Inorganic Clusters II

- **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



Source: Graph adapted from http://www.aims.gov.au/pages/research/projects/sunscreens/pages/sunscreens02.html

Nano-Sunscreen Appears Clear



Source: http://www.science.org.au/sats2003/images/barber-slide3.jpg

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

Source: http://www.smalltimes.com/images/st_advancednanotech_inside_.jpg

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/index.html.

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: ~100-280 nm; UVB: ~280-315 nm; UVC ~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_20) absorbs IR rays
- Ozone (O_3) absorbs some UV rays
- Visible rays just pass through

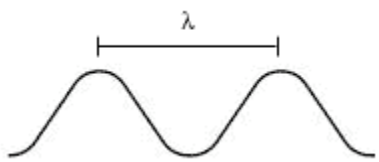
As the ozone layer is depleted, more of the UV light emitted by the sun will reach the earth.

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 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 ~225,563,909 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 (6.26×10^{-34} 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>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 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 <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 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 not 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 <u>actual</u> number of atoms that combine together to form a molecule, the formula unit indicates the <u>ratio</u> 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 & Sunlight Animations: Teacher Instructions & 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 <u>not</u> 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 & 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.

One-Day Version of Clear Sunscreen

Student Materials

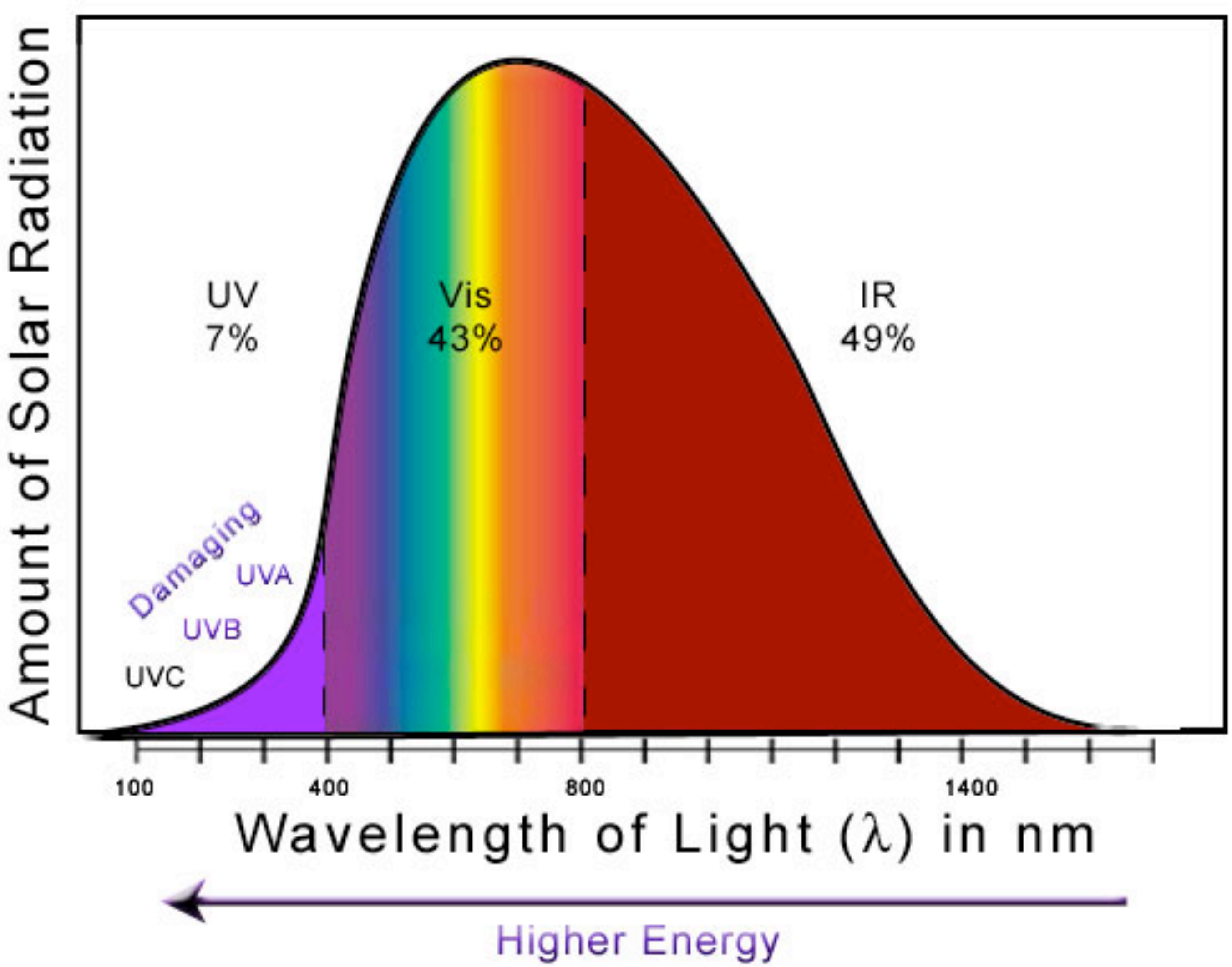
Contents

Summary of Radiation Emitted by the Sun: Student Handout

Chart of Different Kinds of Solar Radiation

Radiation Type	Characteristic Wavelength (λ)	Energy per Photon	% of Total Radiation Emitted by Sun	Effects on Human Skin	Visible to Human Eye?
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
Visible	~400-800 nm	Lower Energy	~43 %	None Currently Known	Yes
IR	~800-120,000 nm	Lowest Energy	~49%	Heat Sensation (high λ IR)	No

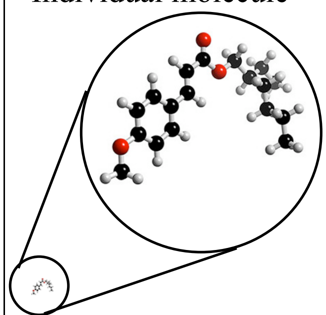
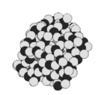
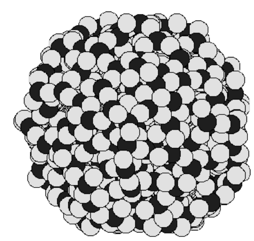
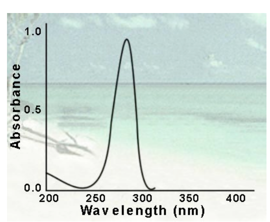
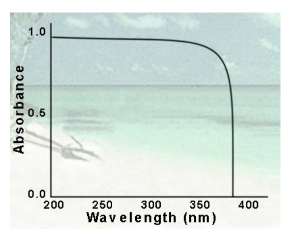
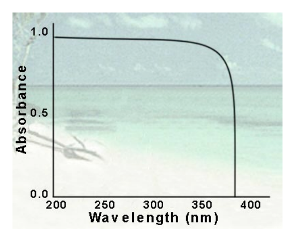
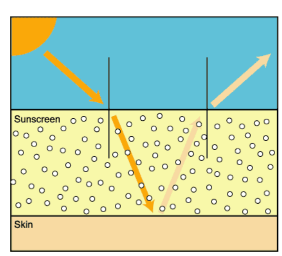
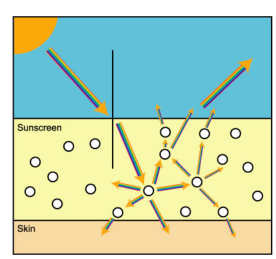
Graph of Radiation Emitted by the Sun by Wavelength



Summary of FDA Approved Sunscreen Ingredients: Student Handout

	λ range (nm)	Protection Against		Possible Allergies	Other Issues
		UVB 280-320 nm	UVA 320-400 nm		
Organic Ingredients					
PABA derivatives					
Padimate O (Octyl dimethyl PABA)	295-340	Good	Little	Yes	-
PABA (p-aminobenzoic acid)	200-320	Good	Little	Yes	Greasy, Stains
Cinnamates					
Octinoxate (Octyl methoxycinnamate) (OMC) (Parasol MCX)	295-350	Good	Little	Yes	-
Cinoxate	280-310	Good	Little	Yes	-
Salicylates					
Homosalate	295-340	Good	Little	Yes	-
Octisalate (Octyl salicylate)	295-330	Good	Little	Yes	-
Trolamin salicylate	260-355	Good	Little	Yes	-
Benzophenones					
Oxybenzone (Benzophenone-3)	295-375	Good	Some	Yes	-
Sulisobenzone (Benzophenone-4)	260-375	Good	Some	Yes	Hard to solubilize
Dioxybenzone (Benzophenone-8)	250-390	Good	Some	Yes	Hard to solubilize
Other Organics					
Ensulizole	290-340	Good	Little	Yes	-
Octocrylene	295-375	Good	Little	Yes	-
Menthyl anthranilate (Meradimate)	295-380	Good	Some	Yes	-
Avobezone (Parsol 1789) (Butyl methoxydibenzoyl methane)	295-395	Good	Good	Yes	If not well formulated, loses potency
NEW Ecamsule (Mexoryl SX)	310-370	Some	Good	Yes	Water-soluble
Inorganic Ingredients					
Titanium Dioxide	upto 365	Good	Good	No	-
Zinc Oxide	upto 380	Good	Good	No	-

Overview of Sunscreen Ingredients: Student Handout

	Organic Ingredients	**Inorganic Ingredients (Nano)**	**Inorganic Ingredients (Large)**
Atoms Involved	Carbon, Hydrogen, Oxygen, Nitrogen	Zinc, Titanium, Oxygen	Zinc, Titanium, Oxygen
Structure (not drawn to scale)	Individual molecule 	Cluster ~100 nm in diameter 	Cluster > 200 nm in diameter 
Interaction with UV light	Absorb specific λ 	Absorb all UV < critical λ 	Absorb all UV < critical λ 
Absorption Range	Parts of UVA or UVB spectrum	Broad spectrum UVA and UVB	Broad spectrum UVA and UVB
Interaction with Visible light	None	Minimal Scattering 	Much Scattering 
Appearance	Clear	Clear	White