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.

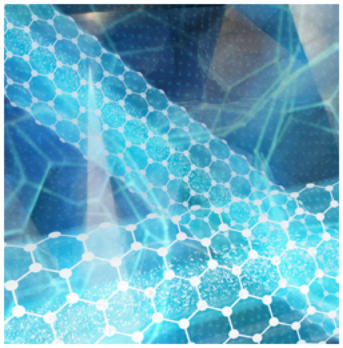
Sunscreen Appearance Timeline (with Ad Campaign Activity)

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

What makes sunscreens with traditional size inorganic clusters appear white?

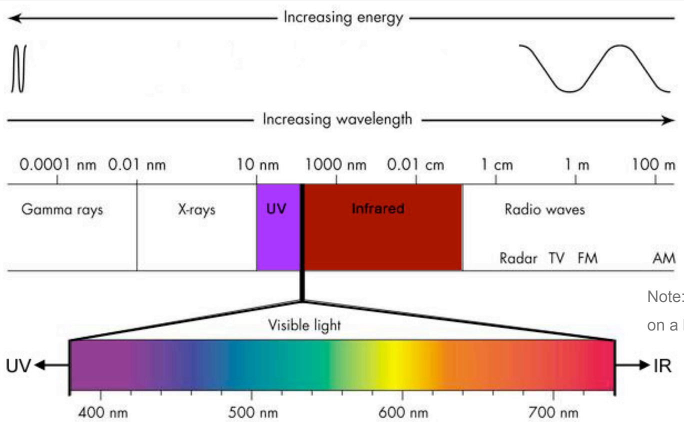
And…

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

…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

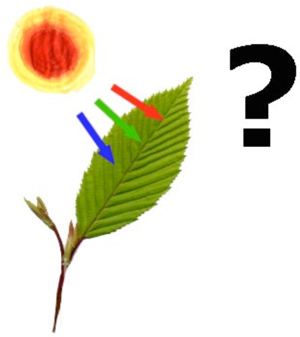
Reflected Light Gives an Object its Color

- **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

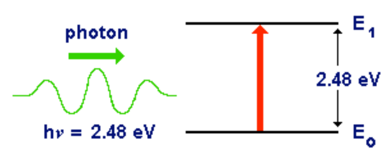
What determines which colors (wavelengths) of visible light are absorbed?



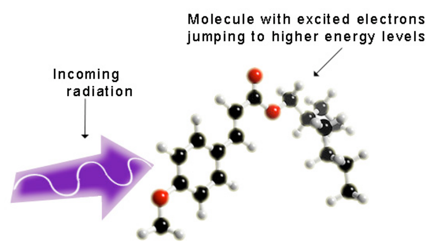
Source: Original Image

The Leaf Molecules' Energy Levels Determine Absorption

- **Only light with the right amount of energy to excite electrons is absorbed**



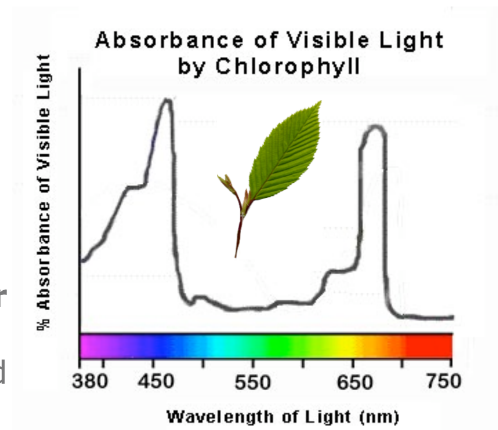
- **Same process as seen for UV light absorption**
  - Different kinds of molecules and inorganic compounds absorb different wavelengths of light



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

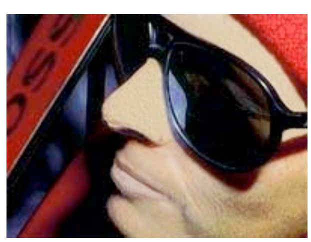
Chlorophyll's Visible Absorption Spectrum

- **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

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



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

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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)

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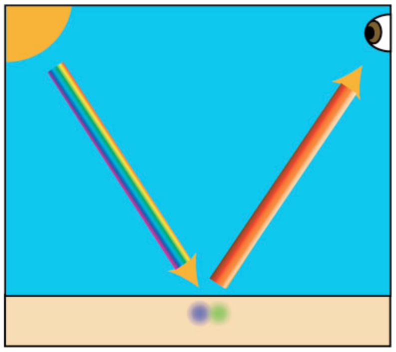
What Do Melanin Molecules Do?

- **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

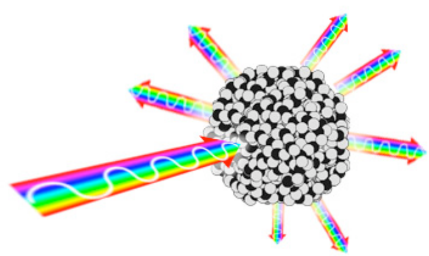


So what makes sunscreens with traditional inorganic clusters appear white?

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**

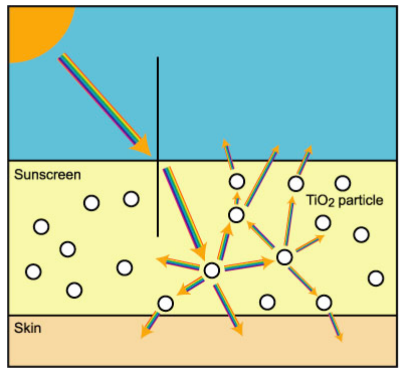


- **The energy from the light is redirected without a chemical interaction with the atoms**
  - This is different than absorption because no energy transformation occurs

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

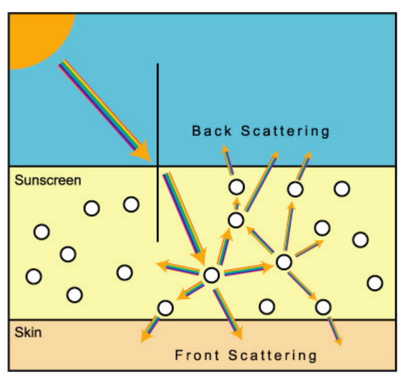


Source: Original Image

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

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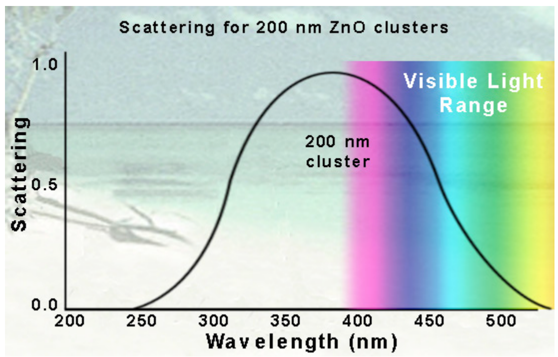
Scattering by Traditional ZnO and TiO_2

- **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

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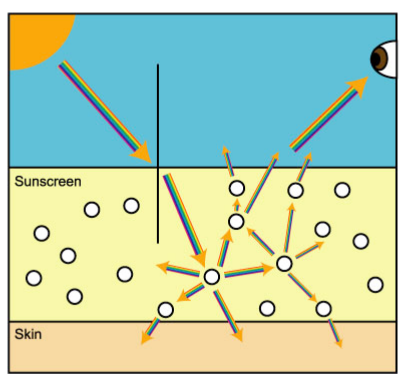
Back Scattered Light Makes the Sunscreen Look White

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



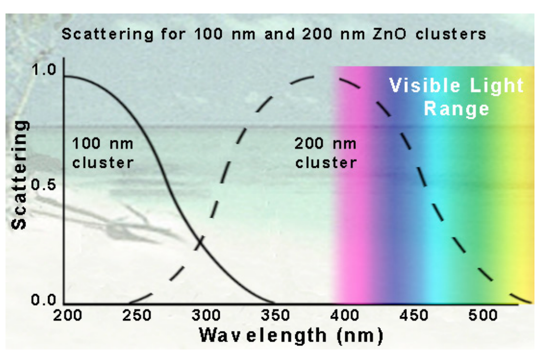
Source: Original Image

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

Nanosized Inorganic Clusters

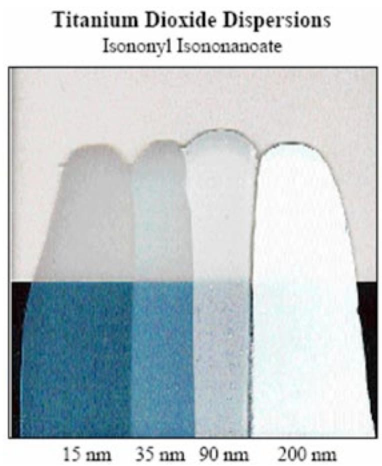
- **Maximum scattering occurs for wavelengths twice as large as the clusters**
  - Make the clusters smaller (100 nm or less) and they won't scatter as much visible light



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

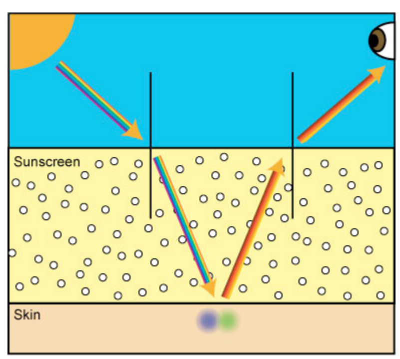


Transparencies of different sized TiO_2 clusters

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

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 when appropriate) correctly shown 50 nm: • All light is only absorbed • UVA / UVB interact the same 300 nm: • Light is both absorbed and scattered • UVA / UVB interact the same	Few or no key aspects of the interaction are correctly shown.	Some aspects of the interaction are correctly shown.	Most key aspects of the interaction are correctly shown.	All key aspects of the interaction are correctly shown.
All relevant blocking mechanisms correctly shown 50 and 300 nm: • Absorption shows light energy being captured by ZnO particles 300 nm only: • Scattering shows light being redirected in multiple directions	Few or no key aspects of the blocking mechanism are correctly shown.	Some key aspects of the blocking mechanism are correctly shown.	Most key aspects of the blocking mechanism are correctly shown.	All key aspects of the blocking mechanism are correctly shown.
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

Category		**Novice (1)** Absent, missing or confused	**Apprentice (2)** Partially developed	**Skilled (3)** Adequately developed	**Masterful (4)** Fully developed
Required Elements • Light source • Human observer • Skin surface • Sunscreen lotion • Suspended ZnO particles • 5 + visible light rays • 10 + frames		0 - 2 of the required elements are present.	3 - 4 of the required elements are present.	5 – 6 of the required elements are present.	All 7 required elements are present.
		Few of the required elements are accurately depicted.	Some of the required elements are accurately depicted.	Most of the required elements are accurately depicted.	All of the required elements are accurately depicted.
Interactions of light rays with ZnO particles (and skin when appropriate) correctly shown		Few or no key aspects of the interaction are correctly shown.	Some aspects of the interaction are correctly shown.	Most key aspects of the interaction are correctly shown.	All key aspects of the interaction are correctly shown.
50 nm: • No scattering • Blue/green light absorbed by skin	• Few or no key aspects of the observer's view are correctly shown.				
What the observer sees and why they see is correctly shown		Few or no key aspects of the observer's view are correctly shown.	Some key aspects of the observer's view are correctly shown.	Most key aspects of the observer's view are correctly shown.	All key aspects of the observer's view are correctly shown.
50 nm: • Skin • Peach/Brown color	300 nm: • Sunscreen • White color				
Teamwork • All team members contributed significantly to the project • Group worked together to manage problems as a team		Few team members contributed to the project.	Some team members contributed to the project.	Most team members contributed to the project.	All team members contributed to the project.
		Group did not address the problems encountered.	Group did not manage problems effectively.	Problems in the group managed by one or two individuals.	Group worked together to solve problems.

Sunscreens & 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: