# 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)

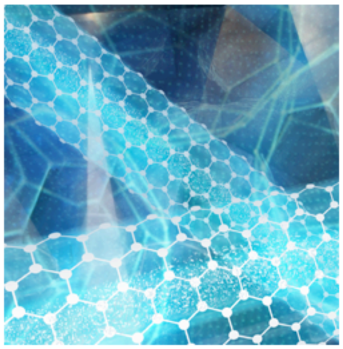
Students will be able to:

*(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<br>(50 min) | Show NanoSunscreen – The Wave of the Future? PowerPoint Slides, using the question slides and teacher’s notes to start class discussion.<br>Perform Demonstration associated with PowerPoint Presentation (optional).<br>Show Animation associated with PowerPoint Presentation (optional).<br>Give out student handouts and discuss as at appropriate parts of the presentation:<br>• Sun Radiation Summary<br>• Summary of FDA Approved Sunscreen Ingredients<br>• Overview of Sunscreen Ingredients | 50 min | NanoSunscreen – The Wave of the Future? PowerPoint Slides & Teacher Notes<br>Computer and projector<br>Optional Demonstration Materials: UV light, different kinds of paper currency.<br>Optional Animation: Download from http://nanosense.org/activities/clearsunscreen/index.html<br>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

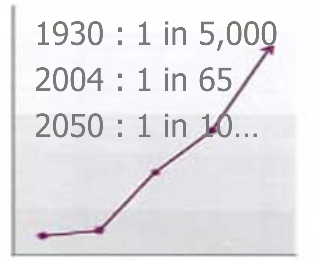
Sources: http://www.oasishospital.org/previousnews.html; http://wohba.com/archive/2005_03_01_archive.html

# 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

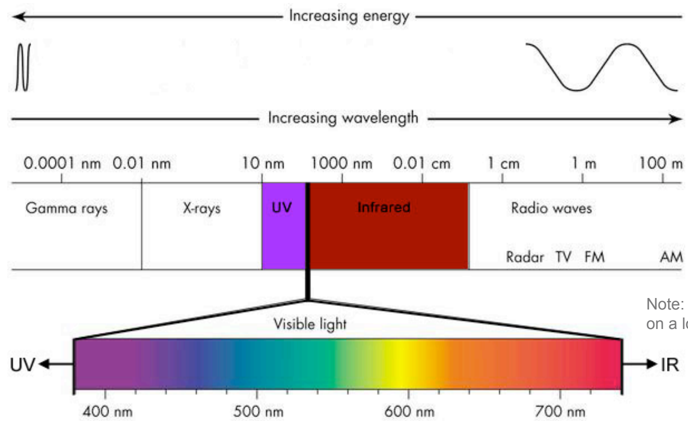


## What are sun rays?

## How are they doing damage?

# The Electromagnetic Spectrum

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



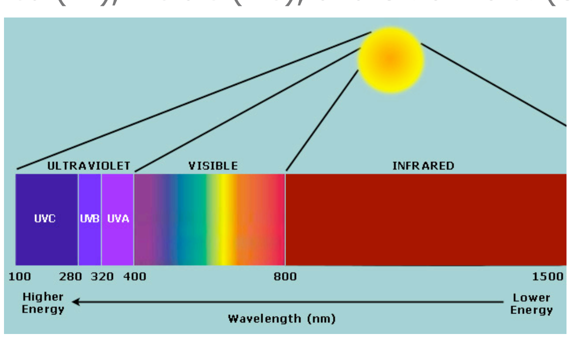

Note: Diagram drawn on a logarithmic scale

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)

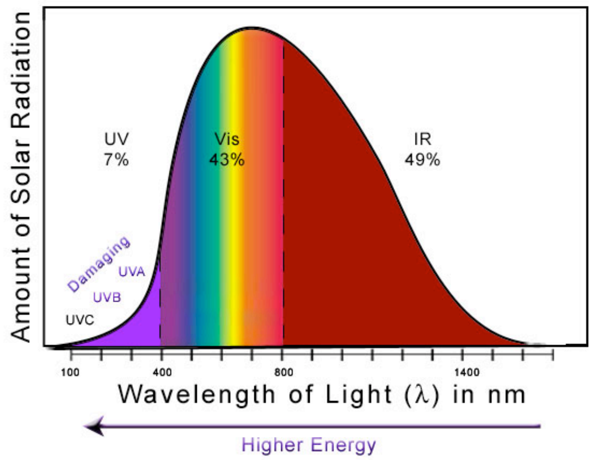



- **Higher energy radiation can damage our skin**

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

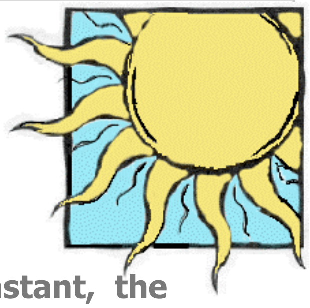


# How can the sun's rays harm us?

# 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

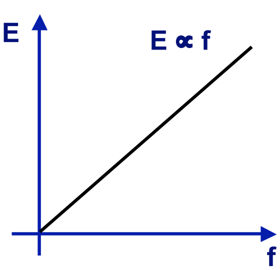


# Radiation Energy I

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)

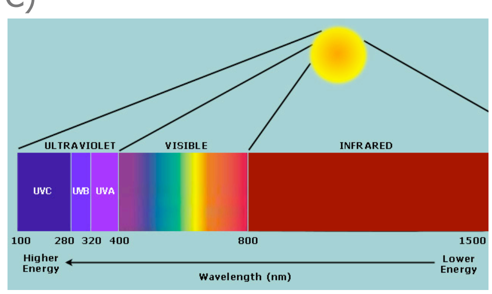

- Total Energy depends on many factors including the intensity of sunlight
- The UV Index rates the total intensity of UV light for many locations in the US daily: http://www.epa.gov/sunwise/uvindex.html

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



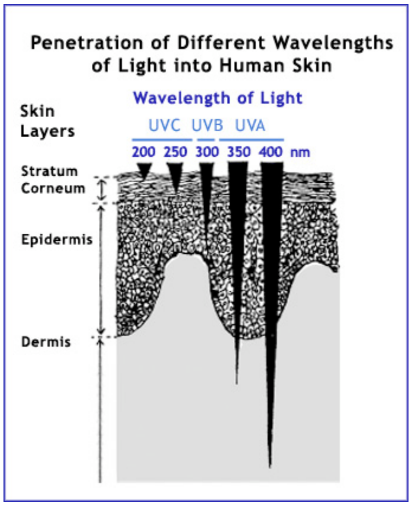
# Skin Damage I

- **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

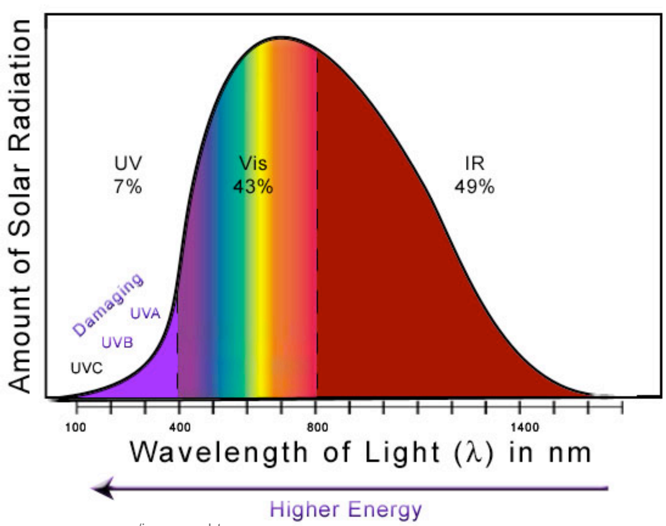



- Very high energy radiation (UVC) is currently absorbed by the ozone layer
- High energy radiation (UVB) does the most immediate damage (sunburns)
- Lower energy radiation (UVA) can penetrate deeper into the skin, leading to long term damage

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<br>High Energy | ~0%<br>(<1% of all UV) | DNA Damage | No |
| UVB | ~290-320 nm (Mid-range UV) | Medium Energy | ~.35%<br>(5% of all UV) | Sunburn<br>DNA Damage<br>Skin Cancer | No |
| UVA | ~320-400 nm (Long-wave UV) | Low Energy | ~6.5%<br>(95 % of all UV) | Tanning<br>Skin Aging<br>DNA Damage<br>Skin Cancer | No |
| Vis | ~400-800 nm | Lower Energy | ~43 % | None Currently Known | Yes |
| IR | ~800-120,000 nm<br>Increasing Wavelength | Lowest Energy | ~49% | Heat Sensation (high λ IR) | No |



# Part 2
# Protecting Ourselves

# What do Sunscreens Do?

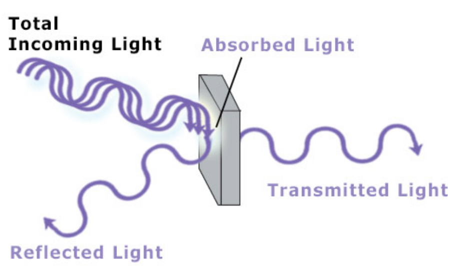
- Sunscreens are designed to protect us by preventing UV rays from reaching our skin
- But what does it mean to **"block"** UV rays?

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

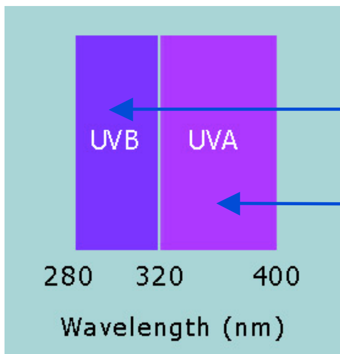
Source: Original Image

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 

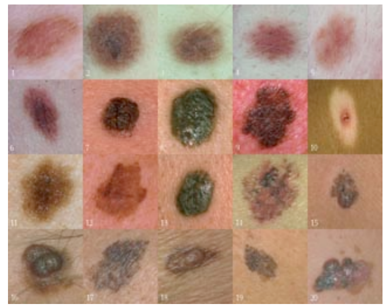
# A Brief History of Sunscreens: The SPF Rating

- **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?

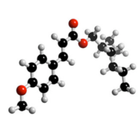
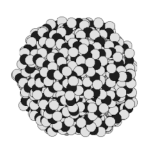
# Know Your Sunscreen: Look at the Ingredients

- **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

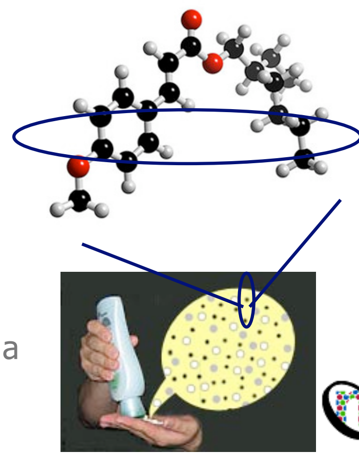
| | Organic Ingredients | Inorganic Ingredients |
|---|---|---|
| Atoms Involved | Carbon, Hydrogen, Oxygen, Nitrogen | Zinc, Titanium, Oxygen |
| Structure (not drawn to scale) | Individual molecule  | Clusters of various size  |
| UV Blocking | Absorb specific bands of UV light | Absorb all UV with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



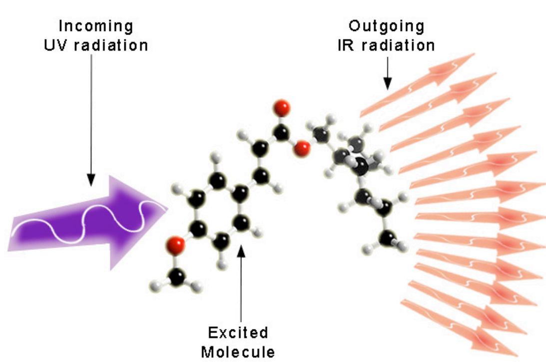
Sources: http://www.3dchem.com/molecules.asp?ID=135# and original image



# Organic Ingredients: UV Blocking

## Organic Sunscreen Ingredients can absorb UV rays

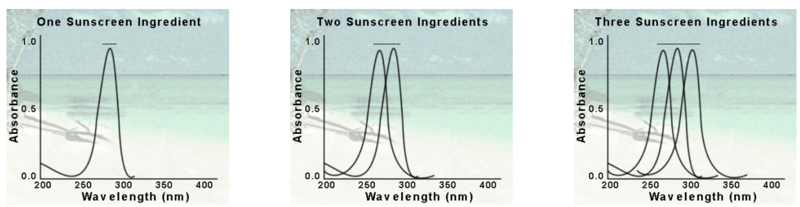
1. Molecules capture energy from the sun's UV rays
2. The energy give the molecule thermal motion (vibrations and rotations)
3. The energy is re-emitted as harmless long wave IR




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



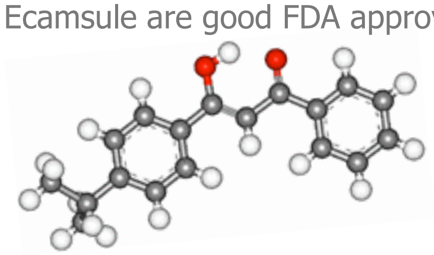

Source: Graphs adapted from http://www.aims.gov.au/pages/research/projects/sunscreens/pages/sunscreens02.html



## 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

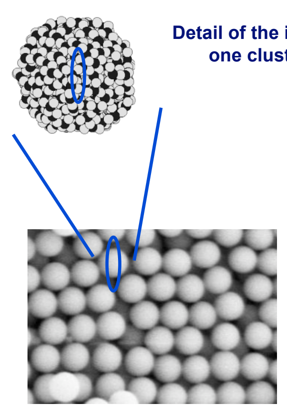
## How are inorganic sunscreen ingredients different from organic ones?

## 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



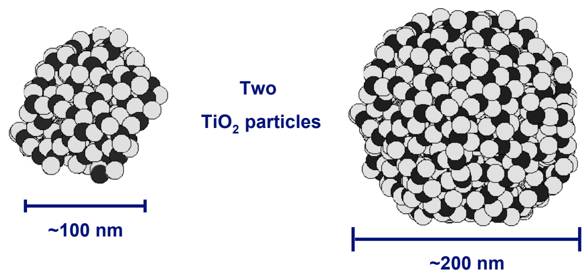
Detail of the ions in one cluster

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

# 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

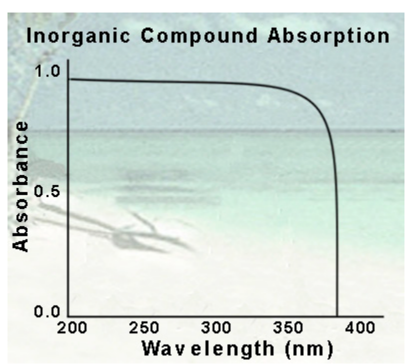



Source: Images adapted from http://www.cse.clrc.ac.uk/msi/projects/ropa.shtml



# 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

# 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



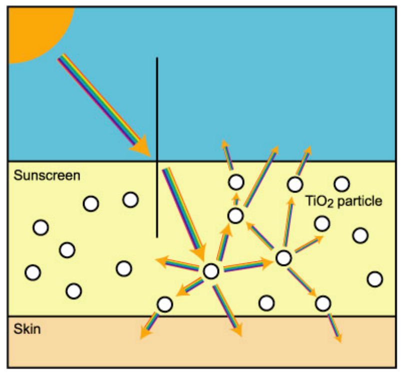
# Appearance Matters

- 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**
  - $\lambda$ > 400 nm
  - This is **visible** light!



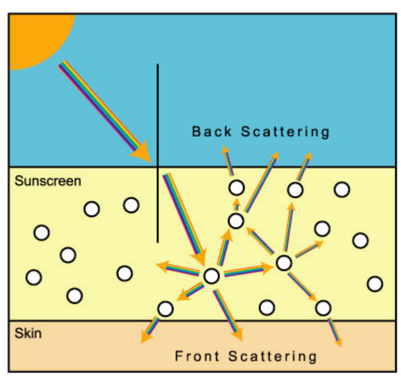

Source: Original Image



## 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

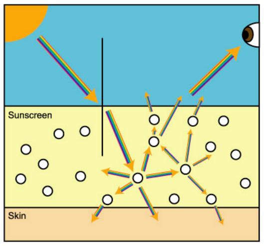


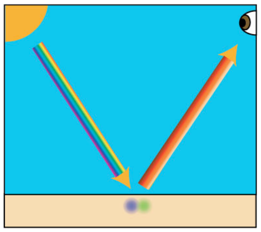

Source: Original Image

## 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



## Why don't organic sunscreen ingredients scatter visible light?

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

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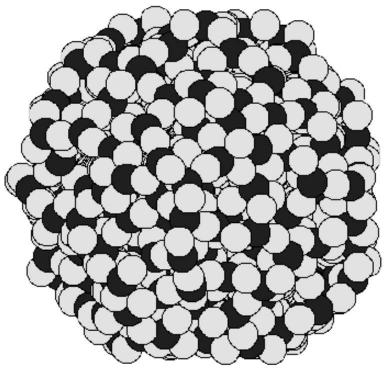
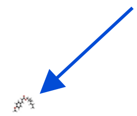
# Organic Sunscreen Molecules are Too Small to Scatter Visible Light





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#

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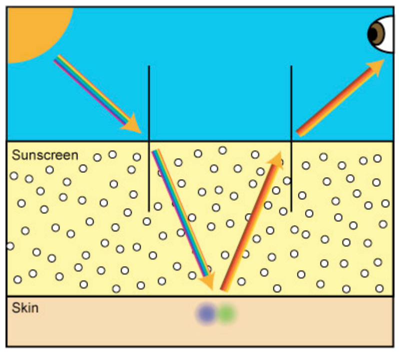
# What could we do to inorganic clusters to prevent them from scattering visible light?

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

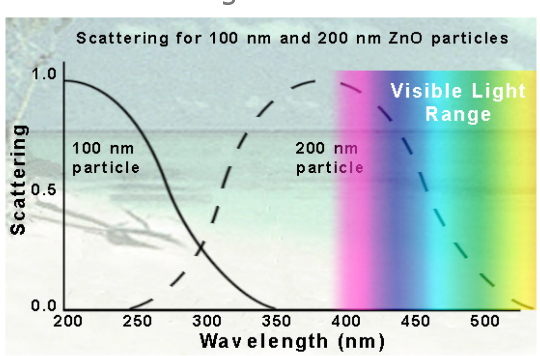



Source: Graph adapted from http://www.aims.gov.au/pages/research/projects/sunscreens/pages/sunscreens02.html



# 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

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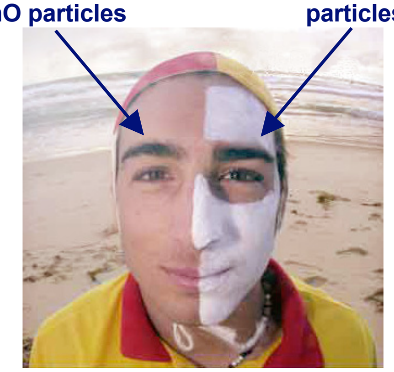
## Nano-Sunscreen Appears Clear




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

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## 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 $\lambda$ of UV light | Absorb all UV < critical $\lambda$ | Absorb all UV < critical $\lambda$ |
| 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

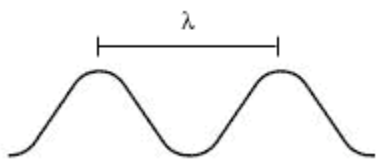
As the ozone layer is depleted, more of the UV light emitted by the sun will reach the earth.

### 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 ($6.26 \times 10^{-34}$ 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 <u>not</u> UV light which is not visible to the human eye). You can demonstrate this effect for your students by turning off the classroom lights and shining a UV light on different kinds of bills and watching the printed designs appear (these must be relatively recently printed; Euros and Canadian bills have particularly interesting designs). If you have two UV lights of different wavelengths, you may even be able to see two different designs due to the selective absorption of the different molecules used in the printing.

### Slide 30: Organic Ingredients: Absorbing UVA / UVB

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

This is a good point to give you students the Summary of FDA Approved Sunscreen Ingredients: Student Handout. Have students look at the different kind of molecules and compounds and see what kind of wavelengths are protected against by which ingredient.

### Slide 31: How are inorganic sunscreen ingredients different from organic ones? How might this affect the way they block UV light? (Question Slide)

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

### Slide 32: Inorganic Ingredients: The Basics

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

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

### Slide 33: Inorganic Ingredients: Cluster Size

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

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

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

### Slide 34: Inorganic Ingredients: UV Blocking

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

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

### Slide 35: If inorganic sunscreens ingredients block UVA light so well, why doesn't everybody use them? (Question Slide)

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

### Slide 36: Appearance Matters

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

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

### Slide 37: Why Do They Appear White? I

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

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

### Slide 38: Why Do They Appear White? II

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

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

### Slide 39: Why Do They Appear White? III

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

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

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

### Slide 40: Why don't organic sunscreen ingredients scatter visible light? (Question Slide)

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

### Slide 41: Organic Sunscreen Molecules are Too Small to Scatter Visible Light

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

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

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

### Slide 42: What could we do to inorganic clusters to prevent them from scattering visible light? (Question Slide)

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

### Slide 43: Nanosized Inorganic Clusters I

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

**Optional Animation:** If you have time, you may want to demo the sunscreen animations for your class at this point. The animations are available at http://nanosense.org/activities/clearsunscreen/index.html and are explained in the Sunscreens & 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.