# Colors at the Nanoscale: Butterflies, Beetles and Opals

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## General Description

### Type of program:

Facilitated activity, classroom activity.

## Program Objectives

### Big idea:

Behavior of light at the nanoscale is different from the macro scale. Visitors will be able to look at how nature produces shimmering iridescent colors using nanostructures. They will be able to understand and appreciate the applications of this process by making an artificial opal.

### Learning goals:

As a result of participating in this program, visitors will be able to:
-Understand that color is produced due to interaction of matter and light
-Structural color is different from pigment based color
-Behavior of light at the nanoscale is dependent on the size of the structures it is interacting with.

### NISE Network content map main ideas:

[x] 1. Nanometer-sized things are very small, and often behave differently than larger things do.

[x] 2. Scientists and engineers have formed the interdisciplinary field of nanotechnology by investigating properties and manipulating matter at the nanoscale.

[x ] 3. Nanoscience, nanotechnology, and nanoengineering lead to new knowledge and innovations that weren't possible before.

[ ] 4. Nanotechnologies have costs, risks, and benefits that affect our lives in ways we cannot always predict.

## National Science Education Standards:

[ ] 1. Science as Inquiry

- [ ] K-4: Abilities necessary to do scientific inquiry
- [x ] K-4: Understanding about scientific inquiry
- [ ] 5-8: Abilities necessary to do scientific inquiry
- [x ] 5-8: Understanding about scientific inquiry
- [ ] 9-12: Abilities necessary to do scientific inquiry
- [x ] 9-12: Understanding about scientific inquiry

[ ] 2. Physical Science

- [x ] K-4: Properties of objects and materials
- [ ] K-4: Position and motion of objects
- [x ] K-4: Light, heat, electricity, and magnetism
- [x ] 5-8: Properties and changes of properties in matter
- [ ] 5-8: Motions and forces
- [ ] 5-8: Transfer of energy
- [ ] 9-12: Structure of atoms
- [ x ] 9-12: Structure and properties of matter
- [ ] 9-12: Chemical reactions
- [ ] 9-12: Motions and force
- [ ] 9-12: Conservation of energy and increase in disorder
- [ x ] 9-12: Interactions of energy and matter

[ ] 3. Life Science

- [ ] K-4: Characteristics of organisms
- [ ] K-4: Life cycles of organisms
- [ ] K-4: Organisms and environments
- [ ] 5-8: Structure and function in living systems
- [ ] 5-8: Reproduction and heredity
- [ ] 5-8: Regulation and behavior
- [ ] 5-8: Populations and ecosystems
- [ ] 5-8: Diversity and adaptations of organisms
- [ ] 9-12: The cell
- [ ] 9-12: Molecular basis of heredity
- [ ] 9-12: Biological evolution
- [ ] 9-12: Interdependence of organisms
- [ ] 9-12: Matter, energy, and organization in living systems
- [ ] 9-12: Behavior of organisms

[ ] 4. Earth and Space Science

- [ ] K-4: Properties of earth materials
- [ ] K-4: Objects in the sky
- [ ] K-4: Changes in earth and sky
- [ ] 5-8: Structure of the earth system
- [ ] 5-8: Earth's history
- [ ] 5-8: Earth in the solar system
- [ ] 9-12: Energy in the earth system

[ ] 9-12: Geochemical cycles
[ ] 9-12: Origin and evolution of the earth system
[ ] 9-12: Origin and evolution of the universe

[ ] 5. Science and Technology
[x ] K-4: Abilities to distinguish between natural objects and objects made by humans
[ ] K-4: Abilities of technological design
[ ] K-4: Understanding about science and technology
[ ] 5-8: Abilities of technological design
[ ] 5-8: Understanding about science and technology
[ ] 9-12: Abilities of technological design
[ ] 9-12: Understanding about science and technology

[ ] 6. Personal and Social Perspectives
[ ] K-4: Personal health
[ ] K-4: Characteristics and changes in populations
[ ] K-4: Types of resources
[ ] K-4: Changes in environments
[ ] K-4: Science and technology in local challenges
[ ] 5-8: Personal health
[ ] 5-8: Populations, resources, and environments
[ ] 5-8: Natural hazards
[ ] 5-8: Risks and benefits
[ ] 5-8: Science and technology in society
[ ] 9-12: Personal and community health
[ ] 9-12: Population growth
[ ] 9-12: Natural resources
[ ] 9-12: Environmental quality
[ ] 9-12: Natural and human-induced hazards
[ ] 9-12: Science and technology in local, national, and global challenges

[ ] 7. History and Nature of Science
[ ] K-4: Science as a human endeavor
[ ] 5-8: Science as a human endeavor
[x ] 5-8: Nature of science
[ ] 5-8: History of science
[ ] 9-12: Science as a human endeavor
[ ] 9-12: Nature of scientific knowledge
[ ] 9-12: Historical perspective

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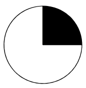
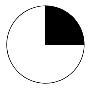
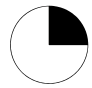
## Time Required

| Set-up | Program | Clean Up |
| --- | --- | --- |
|  |  |  |
| 15 minutes | 15 minutes | 15 minutes |

## Background Information

### Definition of terms

Nano is the scientific term meaning one-billionth (1/1,000,000,000). It comes from a Greek word meaning "dwarf."

A nanometer is one one-billionth of a meter. One inch equals 25.4 million nanometers. A sheet of paper is about 100,000 nanometers thick. A human hair measures roughly 50,000 to 100,000 nanometers across. Your fingernails grow one nanometer every second.

(Other units can also be divided by one billion. A single blink of an eye is about one-billionth of a year. An eyeblink is to a year what a nanometer is to a yardstick.)

Nanoscale refers to measurements of 1-100 nanometers. A virus is about 70 nm long. A cell membrane is about 9 nm thick. Ten hydrogen atoms are about 1 nm.

At the nanoscale, many common materials exhibit unusual properties, such as remarkably lower resistance to electricity, or faster chemical reactions.

Nanotechnology is the manipulation of material at the nanoscale to take advantage of these properties. This often means working with individual molecules.

Nanoscience, nanoengineering and other such terms refer to those activities applied to the nanoscale. "Nano," by itself, is often used as short-hand to refer to any or all of these activities.

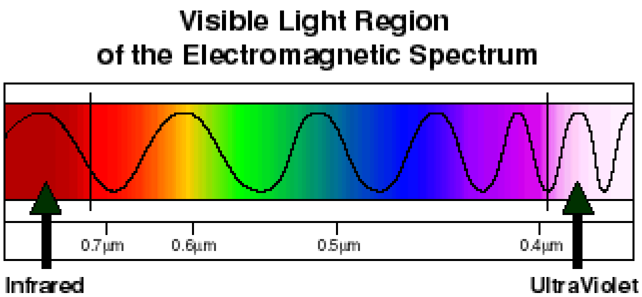
## Program-specific background

In this activity, museum visitors will be exposed to the term ‘Photonic Crystals’. They will see and explore some of the well-known photonic crystals in nature and will also be able observe one method that scientists use in trying to replicate this process.

Light moves in a straight line and color is produced when light interacts with matter. Color can be produced one of two ways- (i) due to interaction of light with matter that has a pigment (dye) of a specific color or (ii) through light being manipulated in its path by the architecture or internal structure of the material. When the architecture is ordered it produces iridescent shimmering color and when disordered, it produces static color (as a result of scattering). Iridescent color is also called structural color. Architectural color is different from Bioluminescence, that several living organism display. Bioluminescence is a form of chemoluminescence and is a result of a chemical reaction within the body of the organism.

There are numerous well known examples of iridescent structural color in Nature. Some of them are the Blue Morpho Butterfly, Jeweled Beetles, Peacock feathers and Opals. They are composed of ordered structures that are repetitive throughout, similar to structures of crystalline materials. Since ‘Photon’ refers to a packet or particle of light, these structures are called ‘Nature’s Photonic Crystals’. The effect of the repetitive ordered arrangement is such that only certain wavelengths are allowed to pass through. This is similar to the way electrons move in a semi-conductor crystal.
As the path of the light within the crystal is also determined by the angle at which the light is incident on the material, photonic crystals show an angle dependent color which leads to a shimmering or iridescent appearance (seen in all of the above examples).

Polystyrene micro-spheres suspended in water can be used to demonstrate of how very small structure that do not have any color of their own can self assemble into ordered repetitive arrangements that will reflect specific colors. The end result of these microspheres is a structure that is very similar to the naturally occurring gemstone opal.
*The color that is produced from the self-assemble microspheres is directly dependent on the size of the microsphere. A good rule of thumb is to choose the diameter of the sphere to be half the wavelength of the color you want to see.* So in order to make an artificial opal that has primarily blue-green color ( 475nm to 525nm or 0.47 µm -0.52µm) you need the microsphere mean diameter to be around 0.24 µm to 0.27µm (240nm to 270nm). For wavelength to color relation, see the visible light color spectrum figure below.




A very simple test for determining structural color from non-structural color is by comparing the Blue Morpho butterfly to the Monarch butterfly. When you put a drop of ethanol on wings of both the butterflies, the Blue in the Blue Morpho butterfly turns green, whereas no color change happens on the wing of the Monarch butterfly. This is because, the structure of the Blue Morpho butterfly has evenly spaced air gaps in them, when you drop ethanol on it the air gaps get filled. Thus light slows down in ethanol and instead of blue color getting reflected back, green color gets reflected back (wavelength of light is inversely proportional to the speed). The wavelength of the light (i.e. color) is determined as a ratio of velocity at which it is travelling and the refractive index of the material. Refractive index in the simplest terms is the inherent ability of a material causing it to affect the path of light.
The real color of the Blue Morpho butterfly wing is brown! Scanning Electron Microscope (SEM) images of the Blue Morpho are available in the Image Collection on NISE Network at http://www.nisenet.org/viz_lab/image-collection.

## Materials

1. Samples of as many as you can find: Opal, Blue Morpho Butterfly Wing, Jeweled Beetles and Peacock feathers.
   Source for Blue Morpho and Jeweled Beetle: http://www.butterfliesandthings.com/
   Additional Info: The specific species of the Blue Morpho they have in stock is not always the same. You can look in their main catalog and find one that suits you best. The catalog name stars with a 'Mor' to designate the species of Morpho. A Monarch butterfly (orange-brown color, "Dan150") butterfly is also recommended as an example of a butterfly that does not have photonic crystals. These are un-spread and un-mounted butterflies. There is an extra charge of $7.00/butterfly to spread the wings, if you have never tried to spread the wings of a butterfly before then it is advisable to get it spread by them.

   The availability of the jeweled beetles also varies, you can look for beetles from the following two species: Curculionidae and Cerambycidae and pick one that has a bright shimmering iridescent color. A series of optical microscope and scanning electron microscope images of a jeweled beetle is attached as a supplemental document that can be printed as a flip book for visitors to browse through.

2. Ethanol,

3. A small dropper or pipette
4. Paper napkins
5. Microscope (Optional): Both butterflies and beetles are very interesting for visitors to look under a simple optical microscope. Visitors will be able to look at the close-up of the wings as well as the scale structure depending on the magnification power of the microscope. A hand held microscope such as this one (http://www.amazon.com/Celestron-44300-HandHeld-Digital-Microscope/dp/B000Q74GUW )can be obtained for $50.00-$75.00. Since these microscopes use a laptop screen as a display, they are great for larger groups of 3-5 visitors . *If you're using a microscope with a light source or a hand held microscope attached to a computer, make sure you have a source of power.*

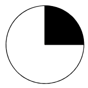
6. Hydrophilic Glass slides: It is necessary that hydrophilic glass slides be used so that the microspheres are able to self-assemble. These can either be bought or if you have chemistry laboratory facilities, they can be made inhouse. See supplemental documents for instructions to make hydrophilic glass slides. http://www.ihcworld.com/products/TruBond-Microscope-Slides.htm (Trubond 380, color white, pack of 100 slides is $49.00)

7. Isopropyl Alcohol: For cleaning the glass slides

8. Polymer Microsphere suspensions (refrigerate if storing over a period of weeks or months, and do not freeze): Polymer microsphere suspension is available from multiple vendors.
    1. Bangs Lab (http://www.bangslabs.com/products/polymer_microspheres): Large variety of sizes are available each 0.5 gm bottle costs about $94.00. For best colors recommended size range is between 0.2 µm to 0.34 µm.
    2. Polysciences Inc (http://www.polysciences.com/Catalog/Department/81/categoryId__373/PageIndex__-1/): Only one size is usable for making Opals (0.2µm mean diameter will have color around 400nm, the next available size is 0.35µm (will produce color around 700 nm), which is very close to IR region and is not best suited for making opals. Each 15ml bottle is $105.00.
9. Transfer pipette for the microsphere suspension
10. Beaker or plastic cup for collecting the waste chemicals (isopropyl alcohol and ethanol)
11. Kim wipes (residue free wipes)
12. Hot Plate: For making opals
13. Black paper or black cloth (optional): You can use this as a background under bright light to 'see' the colors more vividly.

## Set Up

**Time: 15 minutes**



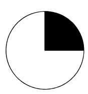
Set out all the samples (Butterflies, beetles and Opals) on a table. Put paper napkins, and ethanol with the butterflies. Keep the microscope along with the butterflies and beetles.

The real opal (if you have one) is best put along with the materials for making the artificial opals (hydrophilic glass slides, isopropyl alcohol, hot plate, Kim wipes and waste container)

Keep the hot plate on low heat (set on 2 or 3 if numbered or around 45-50$^{o}$C if it has temperature markings).

## Program Delivery

**Time: 15 minutes (includes time for people to use the microscope)**



### Safety

-Check temperature of the hot plate to avoid burns
-Wear safety gloves while handling ethanol as well as polymer microsphere suspension

### Talking points and procedure

It is best to have visitors start at one end of the table, so that you can walk them through. The following script is the long version, please adapt to the amount of time you have available.
-Start with the butterflies:
*"Hi, would you like to learn something about butterflies and how color is produced in their wings?* ***Or*** *Do you know the difference between the orange (Monarch) butterfly and the blue butterfly (blue morpho)?"*
*Butterfly wings come in different colors*, (if visitors are young kids, ask them what butterflies have they seen?), *the orange one is called a Monarch butterfly and is a native of California, the blue one is a very famous butterfly from the Amazon forests and is called the Blue Morpho. Can you point out any difference between the two? (*Visitors will typically comment on the shimmering color of the morpho*). The colors that you see in the wings of these two butterflies are very different. (*Here depending on your audience you can include as much or as little you want about interaction of light with matter*) The color in the orange one is similar to the color of your clothing, it is pigment or dye based, so the color is orange/brown. However the Blue*

*Morpho butterfly produces its color in a different way, there are tiny structures, about a ten thousand times smaller than a single strand of your hair, called nanostructures in their wings. When light hits these structures, they will allow only the blue color to be reflected back (*for younger audiences make sure you tell them that light is made up of different colors, like in a rainbow*).*
*Can you guess the real color of its wings? (*The answer is brown*).*
Ask audience to drop ethanol on both wings to see what happens. Explain the reason for color change. They can view the wings structures with a hand-held microscope at this time.
*Jeweled beetles and Opals have a similar structure, Scientist are exploring structures in butterflies, beetles and opals to learn how to control movement of light. These structures have applications in fiber optics, telecommunications and even data transfer! (*Younger kids like to hear about the invisibility cloak application, for more information on this refer to http://news.bbc.co.uk/2/hi/8574923.stm*)*

*Let us take a look at an example of how artificial opals can be made. In this activity we use very small polystyrene spheres that are suspended in water. These are (*size of your polystyrene sphere*) in diameter. When we put a drop of this suspension on a glass slide, as the water dries off, the spheres will self-assemble into a structure similar to that of an Opal. As you can see, the liquid that we put on the slide is white, as it dries on the hot plate, it shows up shimmering colors.*
With gloved hands take a hydrophilic glass slide and clean it with isopropyl alcohol. Wipe dry with Kim wipes. Put the slide on the hot plate and using the pipette put one drop of the microsphere suspension on it. You can use two different sizes of spheres, for example, 0.25 µm and 0.31 µm on the same glass slide. As they both dry they will show up different colors.

## Tips and troubleshooting

1. The micro sphere suspension should be stored in a refrigerator (do not freeze) when not in use.
2. The color that you observe with the microspheres has a wavelength equal to twice the diameter of the microsphere.
3. Once dry the observed color is iridescent and highly angle dependent.  Use a good light source or have a brightly lit area for use.
4. Try to read up on different optical phenomenon such as interference, diffraction and refraction and reflection. A understanding of coloration in thin films (soap bubbles :The incident light is refracted from both the top layer as well as the bottom layer of the soap film and the two refracted light rays interfere resulting in colors) can also help you explain the blue color in butterfly wings.
5. The hot plate temperature is somewhat critical: too cold, the evaporation rate of the liquid is too slow, if it is too hot then the liquid evaporates so fast that the microspheres do not get enough time to self assemble. Good rule of thumb, you should be able to touch it, and it should feel hot but not enough to burn.

**Common visitor questions**

1. Why does the color change when I look at it from different angles? (see background information)
2. Is there any similarity to liquid crystals? (yes, especially the color production in jeweled beetles is similar to liquid crystals.)

## Clean Up

The polystyrene sphere suspension is safe to handle and dispose. If you do have chemical waste it is better to dispose of the ethanol and other waste liquids as chemical waste.

## Universal Design

This program has been designed to be inclusive of visitors, including visitors of different ages, backgrounds, and different physical and cognitive abilities.

**The following features of the program's design make it accessible:**

[ x ] 1. Repeat and reinforce main ideas and concepts

Many examples in nature that exhibit iridescence.

[x ] 2. Provide multiple entry points and multiple ways of engagement

Use both examples in nature as well as the artificial opals that can be made in lab.

[ ] 3. Provide physical and sensory access to all aspects of the program

**To give an inclusive presentation of this program:**

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