COLORS OF NATURE / KIT 4
OPTICS AND ART

HOW DOES LIGHT HELP US UNDERSTAND THE COLORS OF THE WORLD AROUND US?

The **Colors of Nature Kits** are designed to help students explore the question: *how do art and science help us understand the world around us?* Through a series of investigations, students become familiar with core practices of art and science, developing scientific and artistic habits of mind that empower them to engage in self-directed inquiry through the generation and evaluation of ideas. Kit 4 explores this question through the lens of art and optics: the study of light.

A STEAM APPROACH TO EDUCATION (Science, Technology, Engineering, Art, Math)

STEAM is an educational philosophy that seeks to balance the development of divergent and convergent thinking by integrating the arts with traditional STEM fields (Science, Technology, Engineering, Math). In STEAM learning, students engage in projects and experiments that reflect the transdisciplinary nature of real-world problem solving. Rather than focusing on the memorization of content or the repetition of rote procedures, the STEAM approach develops confidence and familiarity with the concepts, tools and methods of scientific and artistic inquiry in an open and exploratory environment driven by student curiosity. The STEAM investigations in this kit are designed to foster creative engagement by promoting individual agency and establishing meaningful connections to students' own lives and interests.

INTRODUCTION / FOSTERING ENGAGEMENT IN ART AND SCIENCE

ART / SCIENCE OVERLAP

Both science and art seek to broaden our understanding of the world around us. Although art and science are often thought of as separate ways of knowing, they are similar in many important ways in principles and practice. Driven by curiosity, creativity and technique, both disciplines contribute new experiences, ideas, and technologies to society and create the foundation of knowledge from which future innovations emerge. The core practices of art and science reveal significant overlap as well: observing, questioning, experimenting, analyzing, and communicating are the means by which both disciplines generate and distribute new ideas and technologies.

CORE PRACTICES of ART and SCIENCE

Observing
Experimenting
Questioning
Analyzing
Describing
Communicating

ENGAGEMENT IN SCIENCE PRACTICE

Young children engage naturally in core science practices. They make observations and test and revise their predictions as they seek to understand how the world around them works (how high can I stack these blocks before they tumble?). But when science is presented in the classroom as isolated facts to be memorized, or procedural steps to copy, students can lose sight of their own capacity to question the world around them, test their ideas, and share their discoveries. Many students, especially girls and people from non-dominant groups, start to view science as rote, passionless, and uncreative. Students who have difficulty memorizing and repeating facts, or making connections to complex systems that don't feel relevant to their daily lives begin to disengage from science. Again, these STEAM investigations should emphasize developing familiarity with the practice and tools of scientific inquiry, rather than on memorizing content or achieving specific results.

ENGAGEMENT IN ART PRACTICE

Similarly, young children almost universally engage in art making. As they learn to handle and control their mark-making tools, the progress from simple scribbles to the development of symbols that represent their understanding of the world. As the complexity of the symbols increase, children begin to aim for realism (of proportion, form, lighting) in their representation.

Around age 9, as social awareness increases, children begin to shift their focus from the expressive pleasure of making art to the results of their work, especially in comparison to the work of their peers. Between age 10 and 13, children decide whether or not they are good at art (as opposed to whether or not they enjoy making art), and it is in this stage of development that many children cease to engage in art-making, believing they do not have the talent to produce "good" (realistic) results. These beliefs are often reinforced by peers and adults who similarly value conventions of realism in western art. When an adult claims "they can't draw," we automatically understand them to mean that they can't draw realistically, not that they can't move a pen across a piece of paper. With continued practice and instruction, nearly everyone can develop skills of realistic representation. Nevertheless, the following STEAM investigations should remain focused on the act of art making itself: an awareness of the opportunities that present themselves and the creative choices that are made in the course of artistic practice. The results of each activity are useful as a record of the process, but emphasis should be placed on the importance of observing, experimenting, and reflecting throughout the process of making.

INSTRUCTIONAL METHOD

We advocate for a STEAM approach that quiets the inner negative voice, focuses on open outcomes, and values student ideas and expression. Foundational to our approach are practices that promote identification with science and art, including using real science and art tools, connecting science and art to everyday life; and offering students the chance to participate in authentic science and art practice.

Give students choices when possible. A sense of agency can increase identification with both art and science practices.

Accept student responses as value-neutral. Most misconceptions that arise can be addressed by directing student attention to key evidence during activities, and prompting further reflection through questions.

Ask questions and encourage discussion and reflection throughout the activities.

Connect activities to everyday practices and student-relevant ideas. To facilitate drawing connections, encourage students to share what they know about the concepts, techniques, and themes throughout the activity and how these relate to their lives.

GUIDING DISCUSSION AND REFLECTION

It is important to establish an environment that encourages imaginative speculation, or thinking outside the box. If students are conditioned to "take things seriously" during classtime, they might not be comfortable offering the creative or humorous answers that are often generated by divergent thinking.

The instructor should continue asking questions to lead the discussion beyond the point where students offer answers that they believe are "correct" or what they think the instructor expects to hear. This can be facilitated by the instructor's willingness to contribute their own playful ideas and follow up with questions that solicit deeper analysis:

What do this fly's eyes remind you of?

They remind me of a disco ball!

What about them is like a disco ball?

What does a disco ball do to light?

What do you think the fly's eyes do to light?

How might this structure benefit the fly?

ASKING QUESTIONS TO DEEPEN ENGAGEMENT

Each investigation in this kit provides:

A central question to focus the investigation, repeated in the header of each page.

Specific questions integrated with the procedural steps of the activity to prompt the discussion, *shown in italics for quick reference.*

Throughout the activity, the instructor should use open questions to guide observation, encourage experimentation, and prompt reflection.

Questions should aim to:

Expand upon an idea:
What else could you do with this? What else could this be for? What else could this mean?

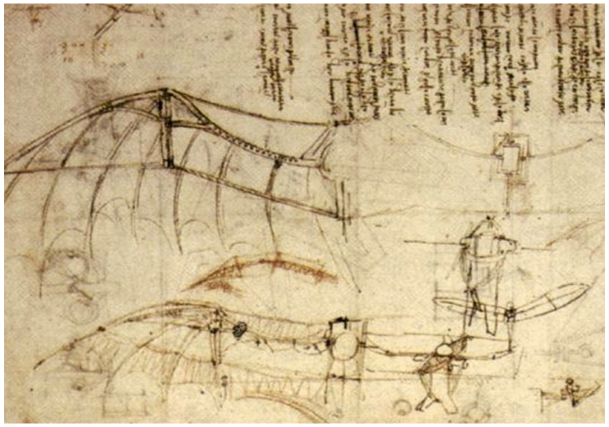
Draw attention to specific details:
What do you see? What texture? Color? Pattern?
What is different/similar between this and that?

Encourage synthesis with existing knowledge:
What does this remind you of?
Where have you seen something like this before?
What about this is different than where you saw something similar before?

NOTEBOOK EXTENSION *30 minutes*

Keeping a notebook is a common practice in both art and science. The notebook is a place to keep track of ideas, observations, measurements, sketches and other information relevant to the ideas the practitioner is exploring. It is a space that allows for informal musings and reflections alongside notes and data recorded for later reference. Each investigation in the Colors of Nature Kits includes suggestions on how to incorporate the notebook into the lesson.

Notebooks can be incorporated into numerous other classroom activities beyond these investigations, providing a private space for students to reflect on what they are learning and develop their ideas outside of the normal constraints of classroom assignments.



Part of a page from one of Leonardo Da Vinci's notebooks, showing a study of the bone structure of a wing, and ideas for the design of a flying machine.

MATERIALS

- Blank student notebooks
- Writing/ drawing tools (pens, pencils, etc.)
- Glue stick

INTRODUCTION

Discuss with students the various reasons why artists and scientists might keep notebooks and how it helps them study the world around them.

Why do artists and scientists keep notebooks?

Some examples include, but are not limited to:

- observing a subject more closely
- recording observations when other methods of recording are not possible or available at the time
- capturing additional information such as measurements, notes, other observations
- keeping a record of what was done, and how data was collected
- thinking through ideas and working out designs on paper before trying in real life

PREPARE NOTEBOOKS FOR USE

Discuss with students what information might be useful to include in their notebook, to assist with identification and use as a reference of their observations. At the very least, have students write their name on the inside cover, so missplaced notebooks can be returned to their owner when found.

What information might be important to include in the notebook?

Some examples could include, but are not limited to:

- name
- contact information
- page numbers
- page titles
- table of contents
- dates of entries or observations
- measurements
- sketches
- questions
- photos or other materials that can be glued in

GRADES
4-6

TIME REQUIREMENT
60 minutes

SCIENCE STANDARDS (NGSS)

This investigation can be used in conjunction with other relevant activities towards fulfulling the following performance expectations:

4-PS4-2. Develop a model to describe that light reflecting from objects and entering the eye allows objects to be seen.

MS-PS4-2. Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.

ART STANDARDS (NCCAS)

VA:Cn10.1.5 Apply formal and conceptual vocabularies of art and design to view surroundings in new ways through art-making.

VA:Cr2.1.4 Explore and invent art-making techniques and approaches.

VA:Cr2.1.5 Experiment and develop skills in multiple art-making techniques and approaches through practice.

VA:Cr2.1.6 Demonstrate openness in trying new ideas, materials, methods, and approaches in making works of art and design.

COLORS OF NATURE / KIT 4

OPTICS AND ART

How does light help us understand the colors of the world around us?

INVESTIGATION 1 /

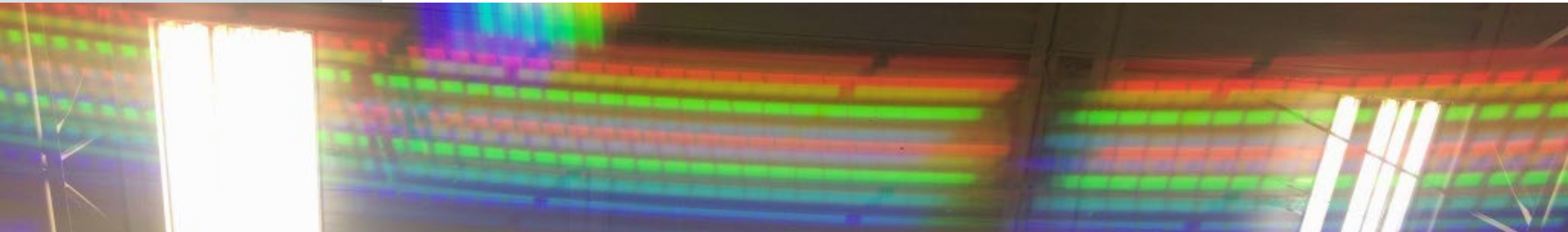
THE COLORS OF WHITE LIGHT

OVERVIEW

In this investigation, students use diffraction gratings to observe and compare the colors that combine to make white light from a variety of light sources. Students then use cameras to document the emitted spectra of these light sources and to compose and capture colorful abstract images.

LEARNING OBJECTIVES

- *Students will be able to discuss how white light can be separated into the colors of the visible spectrum.*
- *Students will be able to explain that light sources emit specific colors or combinations of colors.*
- *Students will be able to use tools such as diffraction gratings to separate the spectra of various light sources into their component colors.*
- *Students will be able to use diffraction gratings, cameras, and various light sources to compose and create colorful photographs.*



INSTRUCTIONAL APPROACH

This investigation is designed to introduce students to **the properties of light that make up the colors of the world around us.**

To foster engagement and development of STEAM-linked identities, we advocate for the sharing and discussion of students' own relevant experiences of color and light, and for providing students with opportunities to make choices based on individual preference throughout the activity, so that they are active participants in their inquiry. The instructor should facilitate student exploration through questions and prompts that encourage:

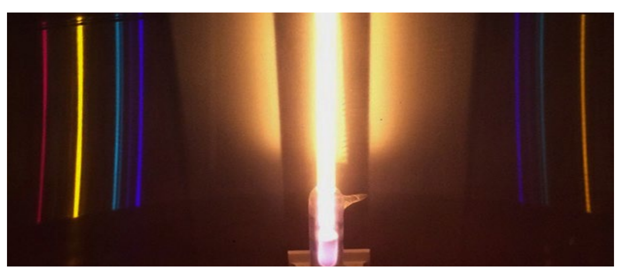
- *consideration of the components necessary to see the colors of the world around us (light, detector, object)*
- *observation of the connection between light and color*
- *observation of the similarities and differences in the spectra of different light sources*
- *experimentation with tools to observe and document the colors emitted by various light sources*
- *consideration of how the color and intensity of light create the distinct shapes that make up photographic images*
- *identification of students' own criteria for a successful photograph*
- *experimentation with the composition of colored shapes within the picture frame to create a photograph of colorful spectra*

The instructor should accept all student answers as value neutral.

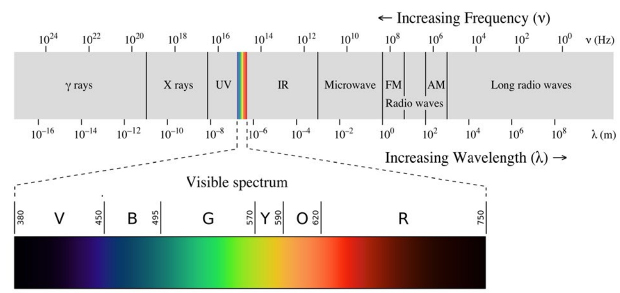
SCIENCE BACKGROUND

The colors we see around us are the result of interactions between **light**, **objects**, and our **eyes**. Color, from a human perspective, is a visual sensation. Specialized cells in our bodies respond to constant physical stimuli and transmit signals to our brain to process and interpret. Like taste, touch, and hearing, sight is one of the ways we collect and process information about the world. To communicate about these sensations, we give them names: we might describe the sensation of tasting something as "salty" or "sweet," or a noise we hear as "loud" or "quiet."

In the same way that we name flavors and sounds to describe specific sensations of taste and hearing, colors are the names we use to describe specific sensations of seeing: a "blue" sky, a "green" leaf, "white" snow. But what actually causes the different visual sensations that we call green, or blue, or white? The answer is light. **Light** is the physical stimulus that specialized cells in our **eyes detect** and respond to, sending information to our brain to construct a mental image of the world around us.



The **electromagnetic spectrum (EM spectrum)** refers to the full range of wavelengths at which light travels. In human eyes, the specialized cells that respond to light are only capable of detecting a small portion of the electromagnetic spectrum. We call this the **visible spectrum**. These cells, called cones, are stimulated by three colors of light: red, green, and blue. When all three kinds of color cones are stimulated, we describe the color sensation as *white* light. The other colors we see are the result of stimulation of various combinations of the red, green, and blue cones. For example, we see yellow when the red and green cones are stimulated simultaneously.



Our primary **light source**, the sun, emits the full spectrum of visible light, as well as wavelengths beyond the visible spectrum that our eyes cannot detect. Other light sources emit spectra that include only certain wavelengths of light. If our eyes are stimulated by light that includes only portions of the visible spectrum, we might experience a different visual sensation that we describe with other color names such as *red, orange, yellow, green, blue,* and *violet,* depending on which wavelengths our eyes detect.

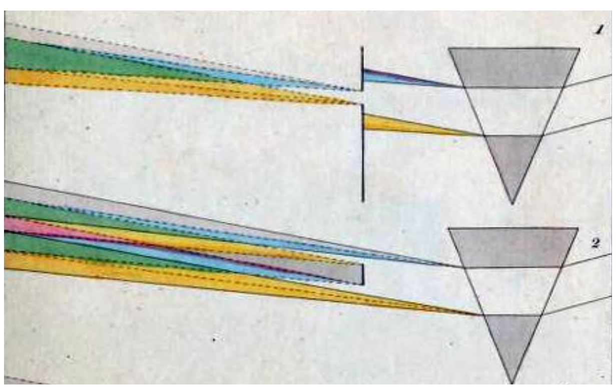
Above, a diagram of the electromagnetic spectrum (by Philip Ronan via Wikimedia Commons). Left, bulbs filled with different gases emit characteristic spectra. The colors of these spectra are visible when the bulb is viewed through a diffraction grating, spreading out the different wavelengths of light.

SCIENCE BACKGROUND *continued*

How do we know that white light is actually a combination of many colors of light? Using tools or materials that interfere with the way light travels, we can spread white light apart so that we see all of the colors it contains. We see this phenomenon occur naturally in many situations, but the most familiar might be when moisture in the atmosphere spreads sunlight into the arcing bands of color we call a **rainbow**.

The tool we will be using today to observe and compare the spectra of different light sources is called a **diffraction grating**. This transparent film contains a pattern of microscopic linear grooves that cause the light to bend, or **diffract**, as it is transmitted through the film. Each wavelength of light diffracts at a slightly different angle, spreading the combined beam from a light source into its component parts.

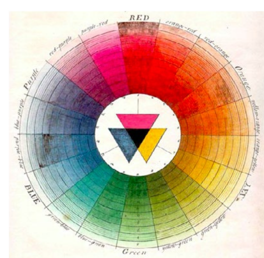
When we observe sunlight through a diffraction grating, we see the full visible spectrum as a continuous rainbow gradient. However, when we observe a flourescent light through a diffraction grating, we see distinct bands of color. Light produced by different materials emit charecteristic spectra which can be used to identify the composition of the light source, such as a star, even at great distances.



ART BACKGROUND

Color is one of the essential elements of visual art. Artists use color to define and differentiate shapes, lines, and forms within a composition, as well as to communicate cultural and emotional meaning. Humans have long sought out materials for their specific colors, and used those materials to represent, interpret, and create images of the world around them.

Although color and vision had been pondered for millennia, with partially accurate theories emerging from various cultures, it was not until the scientific revolution of the 17th century that our modern understanding of color as a property of light itself began to emerge. Isaac Newton published the results of an experiment in which he observed that a circular beam of white light, when passed through a prism, appeared as an oblong rainbow when reflected by an adjacent surface. Using additional prisms, he found he could recombine the colors into a beam of white light. From these experiments he concluded that white light was actually a combination of all of the colors of light, each of which passed through the prism at slightly different angles, spreading the circular beam into a smear of colors.



This discovery prompted intense interest in the subject over the following centuries and many scholars published treatises on color theory, aided by drawings of the optical phenomena they observed and diagrams to support their theories. These developments reframed the way artists understood and employed colors in their work, inspiring stylistic changes and artistic movements.

18th century diagrams of light diffracted through a prism (left) and a color wheel (above).

In art, color can be described as a combination of **hue, saturation** and **value**. Hue refers to the spectral color (red, orange, yellow, etc), saturation refers to the purity of that color, and value refers to the intensity (light or dark or in between) of the color.

Composition, in visual art, refers to the way elements of an image are arranged into a whole. These elements include color, shape, pattern, texture, line, and space. When artists compose an image, they consider how these elements relate to eachother within the frame of the picture.

Photography is the art of creating images with light by exposing light sensitive material, such as film or a digital sensor, using a camera. In a photograph, the composition is bounded by the edges of the picture plane. This boundary can be any shape, but the ease of cutting film and photo sensitive paper into rectangles resulted in a tradition of photographs contained by right angles.

All of the shapes in a photographic composition are defined by variations in the color and value across the picture plane. The photographer considers how these shapes relate to eachother in order to create a unified image. Throughout the process of creating an image, photographers makes compositional choices, from identifying a subject of interest to framing it within the picture plane before capturing it. Afterwards, they make additional choices, such as selecting a particularly successful image from a series of shots, changing how the composition relates to the picture plane by cropping it, or making adjustments to the colors and values. Finally, the photographer decides how to present the image to an audience. Traditionally, photographs were printed on metal plates or paper, but today most photographs are shared on the screens of devices via digital media.

In this activity, we will combine diffraction gratings and cameras to create colorful photographs of various light sources.

KIT MATERIALS

- **Diffraction grating glasses** *(1 per student)*
- **Diffraction grating viewfinder** *(1 per pair of students)*
- **Incandescent flashlights** *(1 per pair of students)*
- **LED flashlights** *(1 per pair of students)*
- **3-colored LED bulbs with remote control in clamp lights** *(3 per class)*
- **EM spectrum handouts** *(1 for every three students)*
- **Colored crayons** *(1 mixed color set for each table group)*
- **Aluminum foil roll** *(about one linear foot per student)*

ADDITIONAL SUPPLIES

- **Camera, or device with camera** *(tablets, smartphones, or any other device with a camera will work, 1 for every pair of students, or small groups as available)*
- **Other light sources around classroom** *(students can seek out additional light sources to observe such as overhead lamps, desk lamps, LEDs on electronics, etc.)*
- **White paper** *(a few sheets per student)*
- **Scissors** *(one pair per group)*
- **Tape** *(1 roll, preferably low-adhesion, such as painters tape)*
- **Notebooks** *(if applicable)*

Many manufacturers produce tri-colored LED bulbs that come with a small remote control to select color settings. The remote can also be used to power the bulb on and off. The clamp light fixture allows the lamp to be set up and aimed in any direction. The push-button power switch on the lamp fixture must be turned on in order to control the bulb using the remote.

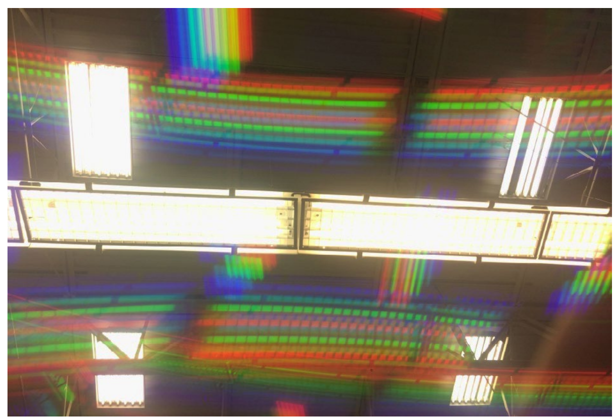
SETUP

1. Assemble materials. Test the camera devices to make sure the batteries are fresh (or charged) and that you are familiar with their operation.

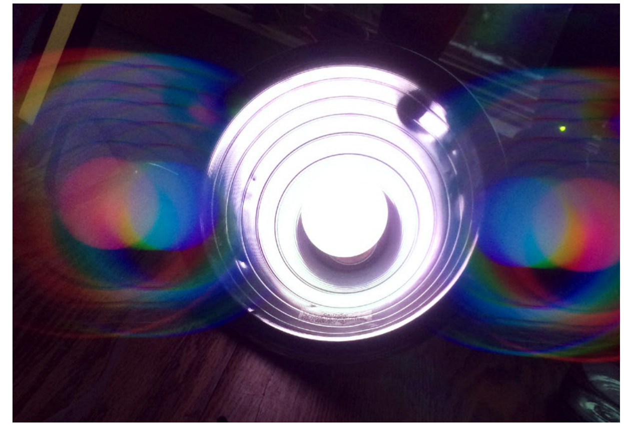
2. Darken room. It does not have to be completely dark, but reducing exterior light helps students see the spectra of the lights they are examining more clearly.

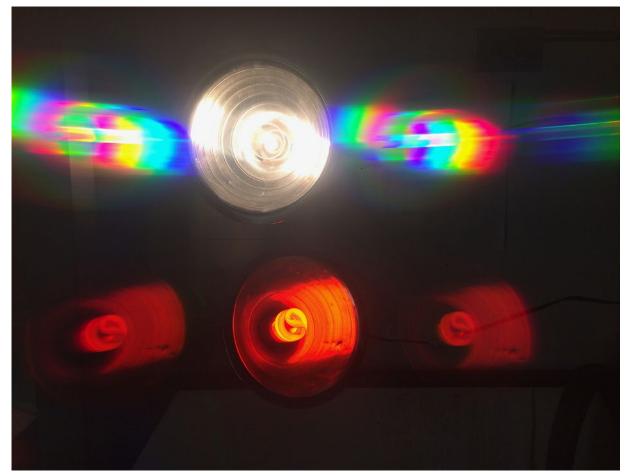
3. Identify and set up three stations in the classroom where the clamp lights with the 3-colored LED bulbs can be attached securely and plugged in. Make sure the cords are arranged and secured so that they will not be a tripping hazard. Test the bulbs, turning them on to the white setting using the remote control.

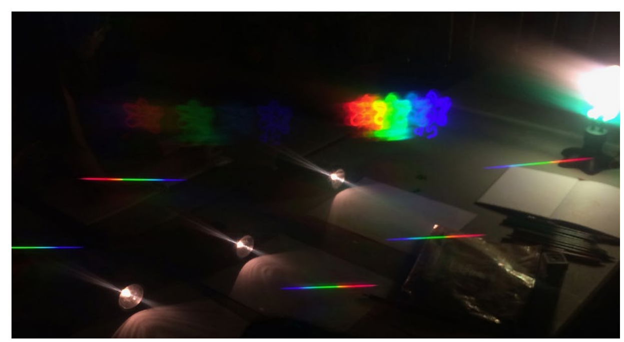
4. Distribute the flashlights (LED and incandescent) and one mixed color set of crayons to each table group.



Various light sources observed through a diffraction grating, which spreads the emitted spectra into their component colors. Above: overhead flourescent lights emit distinct bands of red, green, and blue light. Where they overlap, the colors mix to produce other colors, such as yellow and cyan. Right, top to bottom: a 3-colored LED bulb, containing individual red, green, and blue LEDs; an incandescent bulb which emits a continuous spectrum; a red compact flourescent bulb which uses a filter to block other colors, resulting in a very narrow emission of red light; a white neon light which emits distinct bands of color in red, green, and blue wavelengths, and incandescent flashlights. Left: crumpled aluminum foil used to create interesting shapes of light for photographs.







WHAT IS COLOR? *10 minutes*

1. Engage students by asking them to consider how color is important to their lives:

What are some of the ways you use color in your life?

Do you have a favorite color? What do you like about that color?

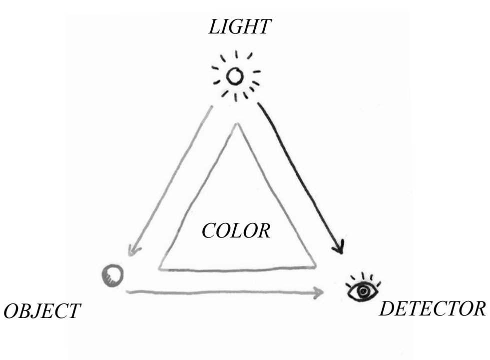
2. Have students take a moment to look around them and notice all of the colors they see. Prompt students to begin an open discussion about color. Encourage students to share any and all ideas about the following questions:

What is color? Where does it come from?

Students might respond with examples of pigment sources (such as: red color comes from beets) but some might also be familiar with the idea that color has something to do with light. All of these ideas are important to this discussion. Collect student ideas about color and let them know that we will be investigating these questions today.

INTRODUCE THE COLOR TRIANGLE *10 minutes*

1. On the board, draw a triangle and let students know that there are multiple essential components involved in how we see COLOR. We will fill in this diagram as we discuss.



DETECTOR

2. Have students locate the crayons on their table. Ask everyone to shut their eyes and, when all eyes are shut, to select a crayon. Keeping their eyes shut, ask:

What color is the crayon you are holding?

3. If students point out that this is impossible to determine with their eyes shut, ask students:

What you would need to add to this situation in order to know what color your crayon is?

4. We are trying to get at the idea that a DETECTOR, such as the eye, is a necessary component of experiencing color. Add this term to the lower right corner of the triangle on the board (you can draw an eye for a representative icon), and prompt students to consider what else might be used as a light detector (for example, a camera).

LIGHT

5. Now, ask students if they have ever been somewhere that was completely dark, so dark that they couldn't see their own hand if they held it in front of their face. Ask them to consider:

If you chose a crayon in that completely dark place with your eyes shut, and then opened your eyes, would you be able to see the color of the crayon?

What would you need to add to the scenario in order to see the color of the crayon?

6. We are trying to get at the idea that LIGHT is a necessary component of seeing color. If students are confused by the direction of the discussion, ask them to consider whether having a flashlight would help them identify the color of the crayon. When students conclude that LIGHT is a necessary component of seeing color, add it to the top of the triangle on the board (you can draw a sun or a lightbulb as a representative icon).

7. Ask students to think about the last time they saw a rainbow, and have them list the colors: red, orange, yellow, green, blue and violet (ROYGBV). Ask:

Where do the colors in the rainbow come from?

Why do they always appear in that order?

Many students are familiar with the idea that the rain somehow interacts with the sunlight to create those colors, and some may even suggest that all of the colors we see are contained in sunlight. If students don't have ideas about where the colors in the rainbow come from, it is ok at this point.

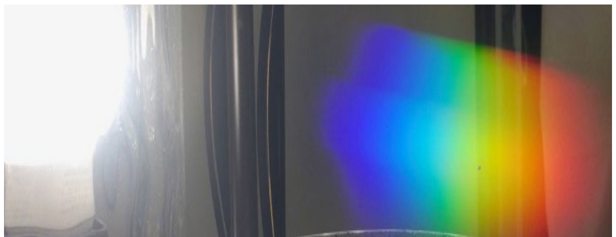
Let students know that today we will be exploring this point of the color triangle: LIGHT.

OBJECT

8. Now, select a red crayon and hold it up for the students to see. Ask students to identify the color. At the lower left corner of the triangle, write OBJECT. Let students know that visible objects have certain properties that determine what color we see when the light that hits them is reflected back to our eye. In this case the object is the crayon, which appears red because of pigments.

In our next investigations we will explore the different ways an OBJECT can interact with light, through its pigments or its structure, to produce the colors we see.

Today our focus is just on LIGHT, and the role it plays in the colors we see in the world around us.



EXPLORE WITH DIFFRACTION GRATINGS *15 minutes*

Students will now be exploring and documenting the spectra of various light sources. This activity will work best if the room is somewhat dark so the spectra of the flashlights are clearly visible through the diffraction gratings, but not so dark that students can't navigate the room safely.

1. Pass out the **diffraction grating** glasses and ask students to examine them carefully, but avoid touching the lenses as the oils from fingers can affect their functionality. Ask:

What do you see? (a clear film, maybe slightly foggy)

2. Now, have students look around the room through their diffraction grating glasses. Ask:

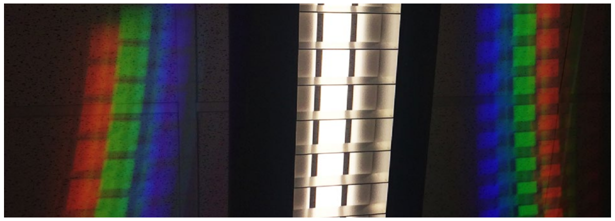
Does anything look different? What do you see?

Students will start to notice that they can see rainbows around light fixtures. Ask students if they have seen anything like this before. Similar to a prism, or moisture in the sky, a diffraction grating spreads out the lightwaves that make up white light as it passes through the material, making a spectrum of colored light visible.

3. Ask students to look at the overhead classroom lights without the diffraction gratings, and to identify the color of light (white). Now, ask students to look at those lights through their diffraction gratings. Ask students to choose a partner and discuss, before sharing ideas with the group:

If the light is white, where are these colors coming from?

Some students are familiar with the idea that white light is made up of all of the colors, and this is why we see a rainbow when moisture in the atmosphere spreads the sunlight apart, much like our diffraction grating does to the overhead lights in the classroom.



An incandescent light bulb (top) and a flourescent light bulb (bottom) viewed through a diffraction grating. The spectrum emitted by the incandescent bulb is a continous rainbow of all the colors of visible light, whereas the spectrum of the flourescent bulb is made up of distinct colors of light, separated by dark areas. Below right, beams of sunlight coming through a window blind. The diffracted spectra are most visible in areas of high contrast, like when seen against the wall which is in shadow.

This is a tricky concept, even when observing the evidence directly. At this point, our goal is just to explore the spectra emitted by various light sources, and make note of the similarities and differences we see.

4. Now, let's observe sunlight through the diffraction gratings. **Remind students *never* to look directly at the sun, as it is harmful to the eyes.** Instead, look at reflected sunlight by observing something white, like a piece of paper. Even if it is a cloudy day, you will still be able to see colorful spectra in high contrast areas (where light and dark are side by side, like looking up at the sky through tree leaves, or around the edges of windows in a darkened classroom). If it is convenient to go outside, you can take the class out to look around at white objects. Otherwise, turn off the classroom lights and gather students around the windows. Sometimes, to increase contrast, it helps to pull the shades, and look at the crack of light around the edges.

5. Ask students to choose a partner and answer the following questions, before sharing ideas with the group:

What colors did you see when you observed sunlight through the diffraction grating glasses?

In what order did the colors appear?

Was this similar or different to what you saw looking at the overhead lights?

If the overhead lights are flourescent, students will notice the colors of the spectra are different than sunlight. Whereas the sun emits a continuous spectrum of all visible colors (ROYGBV), the flourescent bulbs emit a limited combination of specific wavelengths, which appear as bands of bright color separated by dark areas. Using questions, prompt students to notice that even though the colors in each of the spectra are different, the *order* of the colors remains the same, with the violet closest to the light source and the red farthest away.

6. Now, use the remote control to turn on the 3-colored LED bulbs (in the clamp lamps) on the *white* setting. Turn off the overhead lights and have students use the diffraction grating glasses to carefully observe and compare the spectra of the LED lamps to the other spectra they have observed. Ask:

How is this similar or different to what you saw when looking at the flourescent lights? ... the sunlight?

The 3-colored LED bulbs actually contain three individual LEDs, red, green and blue, that combine all together to make white light, or in various mixes to create other colors.

EXPLORE WITH DIFFRACTION GRATINGS *continued*

7. Have students take a few minutes to observe and document the spectra of at least three different light sources through their diffraction grating glasses. Students can work at their tables using the handheld incandescent and LED flashlights, or rotate around the classroom and observe the colored LED lights (in the clamp lamps. They can also look for other light sources in the classroom to document. Common sources are indicator lights on electronics, device screens, desk lamps, exit signage, and so forth.

Students observe and document the spectra of various light sources, viewed through diffraction gratings.

If students are using notebooks, they can use the colored crayons to draw diagrams of the colors they see directly in their book. Otherwise, blank sheets of drawing paper (or copy paper) can be distributed. Remind students to label each diagram with their name, the light source, and any other information, questions or or observations that arise.

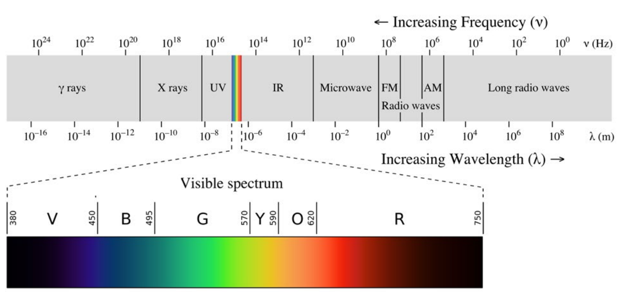
ELECTROMAGNETIC SPECTRUM *10 minutes*

1. Gather students back at their table groups and ask them to share their observations about similarities and differences between the colors of the different light sources they examined using the diffraction gratings.

2. Ask if they have ever heard the term **electromagnetic (EM) spectrum.** Students may not be familiar with the term but are likely familiar with many of the categories of waves that make up the EM spectrum. Distribute the EM spectrum diagrams and have students discuss them at their tables. Ask:

> *What terms do you see that are familiar?* (x-rays, microwaves, radio waves, infrared, UV, etc.)
>
> *What do you notice on this diagram of the EM spectrum that is similar to what you noticed when looking at white light through the diffraction gratings?* (a rainbow of color)

The colors of the visible spectrum are the same colors we see in the rainbows created when observing sunlight through the diffraction grating glasses and occur in the same order, ROYGBV.



The electromagnetic spectrum. Diagram by Philip Ronan via Wikimedia Commons.

3. Let students know that the EM spectrum represents the range of **wavelengths** at which light travels. Although we can **detect** many of these waves with special equipment (radios, xray film), we can only detect a narrow portion of these wavelengths with our own light **detectors**, our eyes.

4. Have students identify on the diagram the part of the electromagnetic spectrum that we can detect with our eyes. We call this portion of the EM spectrum the **visible spectrum**. Even though it is a continuous range of wavelengths, we refer to sections of it with distinct names such as red, orange, yellow, green, blue, violet (ROYGBV).

5. Let students know that the diffraction gratings we are using have a microscopic structure of linear grooves that form a grating, like a tiny oven rack. These grooves cause light to bend, or **diffract**, as it passes through the transparent material. Different wavelengths bend through the grating at slightly different angles, spreading the beam from the light source into its component colors. This bending is also why we see the colorful spectra shifted off to either side of the light source we are looking at.

SPECTRAL PHOTOGRAPHS *15 minutes +*

1. Now, let students know that they will be composing colorful images using another common tool that, like our eye, detects light. Ask students if they have any idea what this light detection tool might be? If they suggest a camera, let them know they are on to something.

2. Ask students what we call the images we make using cameras. The word **photograph** comes from the Greek *photo* (light) and *graph* (drawing). A photograph is a light drawing! The art of photography is the art of composing shapes into a two dimensional image within the boundaries of the picture frame. The edges of these shapes are defined by the contrast between adjacent colors and intensities of light across the image.

3. In an era of mass visual communication via digital media, students will likely have prior experience with creating, editing, and responding to photographic images. Ask students to share:

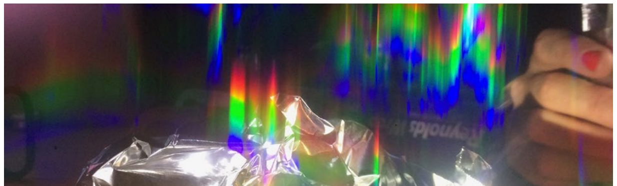
How do you use photographs in your life?

4. Now ask students to share their ideas about what makes a successful photograph. Accept all ideas, writing them on the board as students share. They can expand this list or revise it as they work.

5. Have students consider their criteria for successful photographs and ask them to think about how it might inform their process and choices as a photographer.

As a photographer, what might you consider as you compose and shoot an image?

After the photo shoot, what might you do with the images before sharing your finished work with an audience?

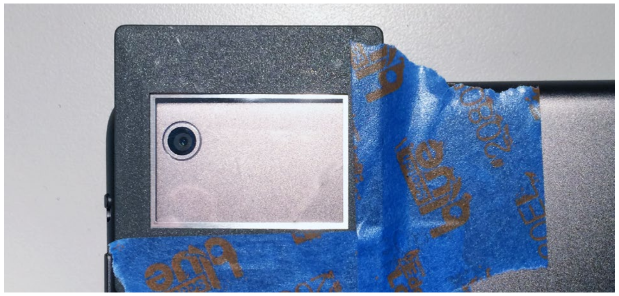


The goal here is to have students make a connection between what they consider a good photograph and the decisions and techniques that a photographer uses to arrive at a desirable result.

6. Let students know they will be working in pairs or small groups to create their photographs. They will take turns being the photographer and the photographer's assistant(s). As the photographer they are responsible for directing the shoot: choosing the subject, framing it within the picture plane, and capturing the image. As the assistant they are responsible for taking directions from the photographer and helping get the desired shot, moving and holding lights and props in place as needed.

7. Let students know that they will each choose and present ONE finished photograph to the class at the end of the activity. They should, however, take multiple photos during their turn as the photographer in order to test and refine their compositional choices. They can choose a final image for presentation from the ones they like, and delete unwanted shots.

8. Now, distribute the camera devices and diffraction grating viewfinders to each pair or small working group (depending on the number of devices available). Demonstrate using tape to attach the diffraction grating so that it covers the camera lens completely.

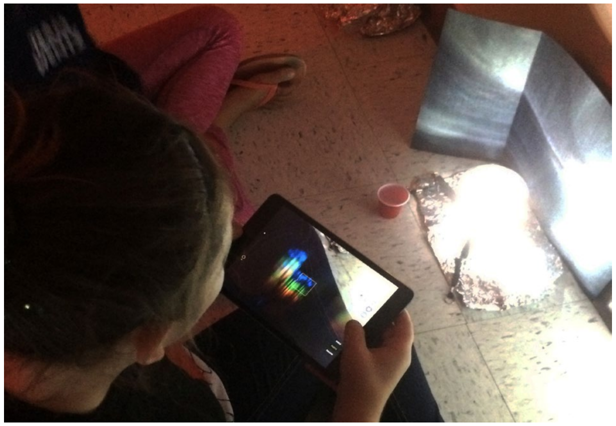


A diffraction grating taped in position over the lens of the camera on a digital tablet.

9. To make sure everyone is on the same page, demonstrate how to focus, capture, review, and delete an image with the camera device they are using.

10. Give each group a foot or so of the aluminum foil. Demonstrate how the foil, or other materials, can be used to manipulate the light (and the colored spectra) to create interesting shapes and patterns to photograph. Crumple the foil and have an assistant shine a flashlight on it. The facets of the foil create numerous shapes of light that can then be photographed through the diffraction grating.

11. Let students know that they can use any of the lights, flashlights and other materials in the classroom (as appropriate) to create interesting effects to photograph. The foil is only one example of how additional materials can be used to manipulate the light. Another idea is cutting shapes out of paper to mask the light source. The possibilities are endless, so encourage students to experiment with other materials in the classroom to create their photographs.



Students experimenting with a clear cup of water and tinfoil to change the shape of a flashlight beam. They have used a piece of black paper as a backdrop for their photo, eliminating distracting shapes and materials in the background and to focus their composition on the shapes of the diffracted light.

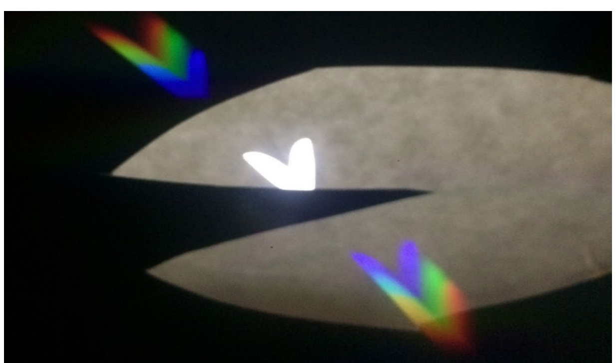
SPECTRAL PHOTOGRAPHS *continued*

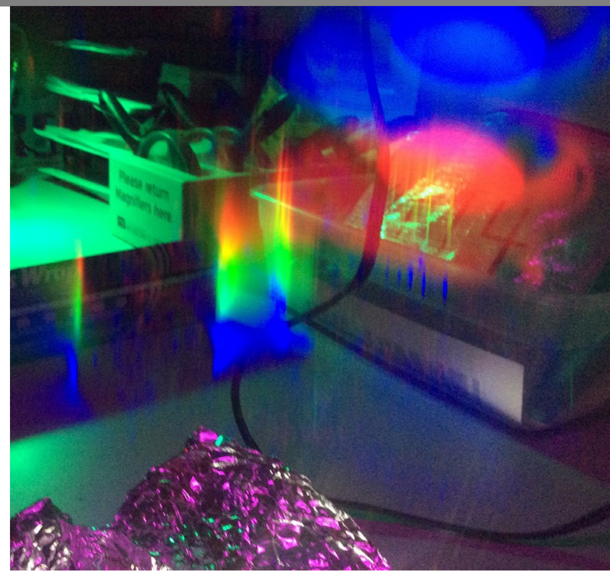
12. As students work in teams, encourage them to consider their personal criteria for a successful photograph in order to help them make intentional choices as they set up and manipulate their light sources, and as they frame each shot they capture.

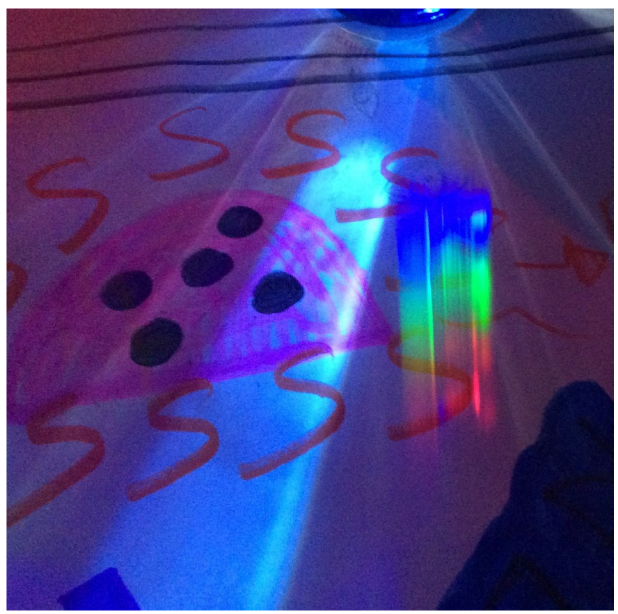
13. When teams finish their shoot, have each photographer choose one photo to present to the group. If the camera devices have editing options within the software, students can even fine tune their image by cropping it to enhance the composition. Photos can also be cropped manually if printed, using a ruler to establish the crop lines and a cutting blade or scissors to trim the image.

PRESENTATION NOTE: Depending on the time and resources available, the photographs can be presented in a number of formats. The simplest way is to display the photos directly on the screen of the camera device, which students can hold or set out on tables for presentation. Photos can also be collected into a combined folder and projected as a slideshow, or posted to a class webpage. If a printer is available, the final photographs can even be printed and hung for display.

14. Students can tidy up the classroom and put away supplies while the final images are compiled for presentation.







Finished photos (above, and right) combine the colors and shapes of the diffracted spectra with other materials used to add interest to the composition.
Left: paper is cut out and used to mask the beam of a flashlight, resulting in interesting colored shapes of diffracted light.

PHOTO GALLERY *10 minutes*

1. Have students gather to present and view their final photographs.

2. As students present, have them briefly discuss the choices they made and techniques they used to capture the image:

What are the light sources in this image?

What did you do to create the shapes and colors we see?

What choices did you make about the composition as you framed and shot your image?

If you were to change anything about this photograph to improve it, what would you change?

3. Encourage the group to give constructive feedback to the presenter, including what aspects of the photo they like and any ideas for alternate approaches to the composition.

GRADES
4-6

TIME REQUIREMENT
60 - 90 minutes

This activity can be condensed into one class period if needed, by moving quickly. However, providing ample time for exploration of the colored lights and production of set designs will deepen engagement and understanding.

SCIENCE STANDARDS (NGSS)

4-PS4-2. Develop a model to describe that light reflecting from objects and entering the eye allows objects to be seen.

MS-PS4-2. Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.

ART STANDARDS (NCCAS)

VA:Cr2.1.4 Explore and invent art-making techniques and approaches.

VA:Cr2.1.5 Experiment and develop skills in multiple art-making techniques and approaches through practice.

VA:Cr2.1.6 Demonstrate openness in trying new ideas, materials, methods, and approaches in making works of art and design.

VA:Cr3.1.4 Revise artwork in progress on the basis of insights gained through peer discussion.

COLORS OF NATURE / KIT 4

OPTICS AND ART

How does light help us understand the colors of the world around us?

INVESTIGATION 2 /

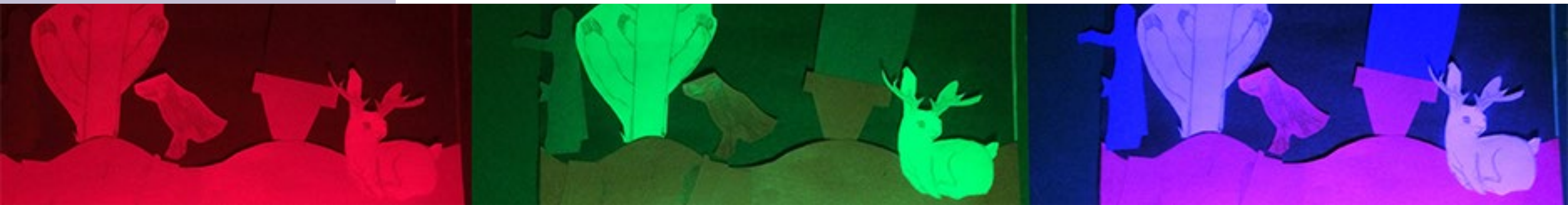
REFLECTION + ABSORPTION

OVERVIEW

In this activity, students explore how light interacts with objects through reflection and absorption, resulting in most of the colors we see in the world around us. Students then apply their knowledge of reflection and absorption to develop models of dynamic set designs that change when viewed under different colored light sources.

LEARNING OBJECTIVES

- *Students will be able to explain that objects can absorb some colors of light, while reflecting others.*
- *Students will be able to explain that the colors we see when observing an object are the colors of light reflected by that object and detected by our eye.*
- *Students will be able to apply their knowledge of reflection and absorption to create a design proposal for a stage set intended to change when illuminated with different colored light sources.*
- *Students will present their designs to peers and be able to communicate about their design solutions.*



INSTRUCTIONAL APPROACH

This investigation is designed to introduce students to the **interactions of light** with **objects** that result in most of the **colors we see in the world around us.**

To foster engagement and development of STEAM-linked identities, we advocate for the sharing and discussion of students' own relevant experiences of color and light, and for providing students with opportunities to make choices based on individual preference throughout the activity, so that they are active agents of their own inquiry. The instructor should facilitate student exploration through questions and prompts that encourage:

- *observation of changes in perceived color of an object under different light sources*
- *making and testing predictions about the perceived color resulting from specific combinations of objects and light sources*
- *application of knowledge of absorption and reflection to create changing areas of contrast in set designs*

The instructor should accept all student answers as value neutral.

SCIENCE BACKGROUND

When light hits an object it is either **absorbed** by, **reflected** by, or **transmitted** through the object. The optical properties of the object determine how it interacts with different wavelengths of light, and our eye detects the result as a combination of **color**, **brightness/darkness**, and **opacity/translucency**.

The light reflected by an object is the light that reaches our eye, allowing us to see the object. The specific wavelengths (or colors) of reflected light determine the color we see. An object that reflects most of the light that strikes it will appear **bright** to us.

When an object absorbs light, the light becomes thermal energy, or heat. An object that absorbs most of the light that strikes it will appear **dark** to us, since it is reflecting very little light back to our eye. The conversion of light energy to thermal energy is one of the reasons people avoid wearing dark colors on hot sunny days: they make you even hotter.

Finally, light transmitted by an object is passed through to the other side. This is why we can see objects beyond a pane of glass. The glass transmits most of the light reflected by objects on the other side, which is then detected by our eye.

Many of the colors we see in the world around us are not fixed properties of objects, but the result of a dynamic interaction between an object and light source.

When we talk about the colors of things, we usually refer to the colors we see when observing the world under our most common light source, the sun, which emits the full visible spectrum (all colors of light combined are called *white light*). So when we say "this strawberry is red," we mean that we see red when the strawberry is illuminated by white light.

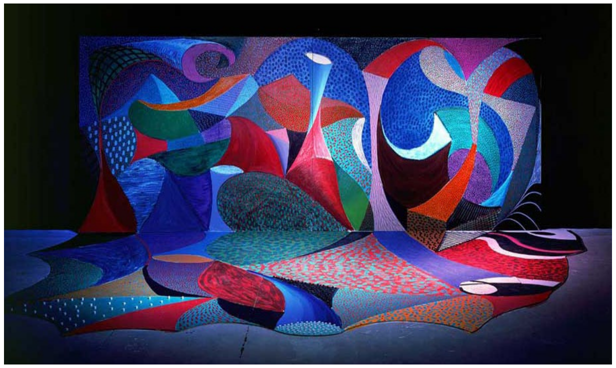
The pigments in the strawberry ***absorb*** *most of the colors of the visible spectrum* contained in white light but **reflect** *red light*. The light that then reaches our eye is red light, and we see the strawberry as red. But if we illuminate the same strawberry using a light source that emits *only green light*, our strawberry will *absorb most of the light* that hits it and the absence of reflected light (there is no *red light* to reflect) will make the strawberry appear dark to our eye.

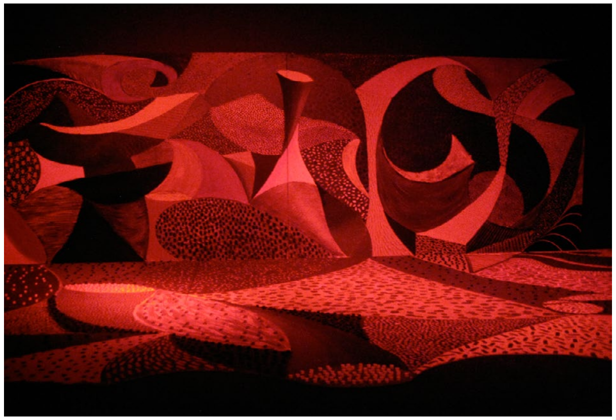
In our previous investigation we used diffraction gratings to observe how different white light sources can actually be made up of slightly different colors of light. Today we will use light sources that emit very limited ranges of color to further explore reflection, absorption, and their effect on our perception of color.

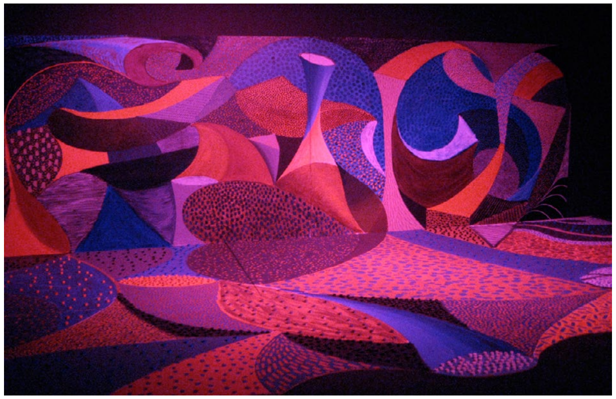
ART BACKGROUND

As an essential element of our visual perception of the world, light plays an enormous role in our experience of art. The colors of light emitted by various light sources, and their resulting effect on the colors of objects that we see, are studied and applied widely across the fields of art and design. Museums carefully choose wide-spectrum white lighting for their galleries in order to maximize the color range we see when viewing a painting, while theater designers select colored lighting to give us clues about the context and mood of a scene.

The brilliantly colored lights of a theater production might seem highly artificial, but we experience similar color changes in the natural and built environment as we move through different spaces and as the sun's location changes throughout the course of the day. Think of how the colors we see in a landscape differ between a clear midday, the glow of sunset, and a moonlit night. Our experience of these changing colors, and certain familiar patterns like the rosy light of dawn, carries emotional connotations that can be evoked with colored lighting.







Right: "Snail Space with Vari-Lights, Painting as Performance," an installation at the Smithsonian American Art Museum by David Hockney. Hockney dedicated his career to exploring color theory and the role of optics, and optical devices, in the history of art. His early work as a set designer for operas informed this installation where he combines an automatic rotation of colored theater lighting with large scale painting to create a dynamic visual environment. The focal points, forms and textures appear to change as the changing lights affect the perceived colors.

By changing the colors of light that hit an object, we change the colors of light that are reflected to our eye.

In this activity, we will first explore how colorful objects absorb and reflect light differently. Using lamps that emit mostly red light, we will create an environment in which the objects that reflect red light appear brightly illuminated, while objects that absorb most red light appear dark.

In our visual experience, relative lightness and darkness creates **contrast** between different forms and the surrounding space, allowing us to see objects as distinct from one another. The effect of colored lighting on the relative brightness and darkness of differently colored objects can alter which shapes we see distinctly in contrast with shapes around it, and which shapes blend in to their surroundings.

Theater designers use the varied reflection and absorption properties of colored objects in their set design to change how the set appears to the audience when illuminated with specific colors of lights. When colored lights are changed during the production, different areas of the set appear lighter or darker, changing the focal points of the set and altering the mood of the scene.

KIT MATERIALS

- **9 x 12” colored construction paper: black, red, green, blue** *(one of each color per student)*
- **Tri-color LED bulbs, remote control, and clamp lights** *(3 per class)*
- **Diffraction grating glasses** *(1 per student)*
- **Multicolor set of wax crayons, paper labels removed** *(3 sets per class)***.** Each set should include one or more each of red, orange, yellow, green, blue, violet, black and white crayons.

ADDITIONAL SUPPLIES

- **Blank paper** *(copy paper or drawing paper, 1 per student)*
- **Scrap paper** *(enough to protect tables while gluing)*
- **Scissors** *(1 per student)*
- **Glue sticks** *(1 per student)*
- **Extension cords may be needed for light set-up**
- **Black garbage bags and painter’s tape may be needed to cover light leaks in classroom**
- **Notebooks** *(if applicable)*

The tri-colored LED bulbs come with a small remote control (above) to select color settings. The remote can also be used to power the bulb on and off.

The clamp light fixture (right) allows the lamp to be set up and aimed in any direction. The push-button power switch on the lamp fixture must be turned on in order to control the bulb using the remote.

SETUP

1. Darken the classroom. For this activity to work effectively, aim to block out as much external light as possible. Heavy black garbage bags and painter’s tape can be used to block windows and other light leaks.

2. Set up three working stations around the classroom by clamping each LED lamp securely above a working area that can accommodate one third of the class (such as a large table or table grouping) and that has access to a power outlet (extension cords or a power strip might be needed to facilitate this). Position and secure any electrical cords so they are not a tripping hazard in a dim room (run cords along walls or under furniture, and tape them down).

3. Turn on lamps at fixture. The bulbs can be turned on/off using the remote control. Set all three to RED with the remote control.

4. Assemble materials. At each station, distribute blank paper and a mixed color set of the wax crayons (labels removed) at each table. Each set of crayons should include a mix of red, orange, yellow, green, blue, and violet plus a black and white.

5. Turn off overhead lights to test set up. Make sure the room is dark enough that the crayons’ normal color is undetectable under the red light, and that the lamps are positioned so as to illuminate enough working space for each table group.

Right: Multicolored crayons viewed in red light. appear lighter or darker depending on what wavelengths of light their pigments absorb and reflect.

RED LIGHT INTRODUCTION *10 minutes*

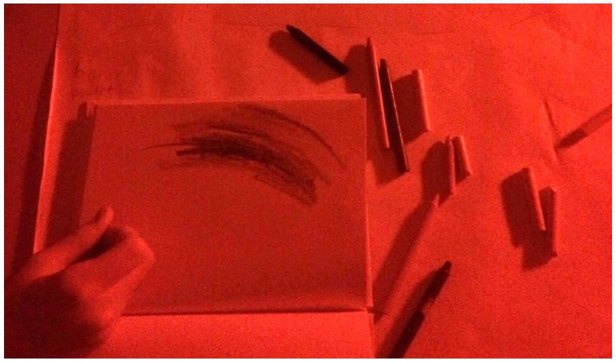
Note: this activity requires a VERY dark space in order to produce the intended effect.

1. Before students enter the room, use the remote control to set each LED lamp to the pure RED mode, and turn off the overhead lighting.

2. Let students know they will be working in a dimly lit space throughout this class period, and ask students to suggest (and commit themselves to) behavior that will maintain a safe working environment.

3. Invite students to enter the room and gather around the work stations. Have students describe the colors of the crayons they see in front of them. They will notice at this point that colors look pretty weird, but that some colors seem easier to identify than others.

4. Now, challenge students to use the crayons provided to try to draw an accurate rainbow (have them call out the colors of the rainbow as a group: red, orange, yellow, green, blue, violet) on a piece of the blank paper, or in their notebooks if they are keeping them.



RED LIGHT INTRODUCTION *continued*

5. When students are finished, ask:

Which colors do you think were the easiest to identify?

Which colors do you think were the hardest to identify?

What do you think your rainbow might look like under white light?

6. Once students have shared their ideas, turn on the overhead white lights.

7. Ask students to share (or discuss) their red-light rainbow drawings:

What colors appear different than what you expected?

Which colors of crayons were hardest to identify under the red light? Why?

Which colors were easy to identify?

Allow students to share their ideas about why some colors might be easier to identify in the red light than others, and accept all answers.

8. Now, ask them to consider:

What colors of crayons do you think will be easiest to identify if we change the light source to GREEN? Why?

Let students know that we will try the GREEN light shortly, but first let's discuss what we think is happening when we view the crayons under the RED light. Turn on the overhead lights for this discussion.

Right: Viewed through a diffraction grating, we can see that the red LED (above) emits a very narrow spectrum of mostly red light, while the white light of an incandescent bulb (below) emits a continuous spectrum of colors from red through violet.

DISCUSS: WHAT IS GOING ON? *15 minutes*

1. To help students think through this question, remind them of the previous exploration, where they examined the spectra of different light sources using diffraction gratings. Pass out the diffraction grating glasses again and have students examine the overhead lights. Ask:

What colors of light do you see? (the diffraction grating spreads the white light into a rainbow, demonstrating that white light contains all of the colors of the visible spectrum)

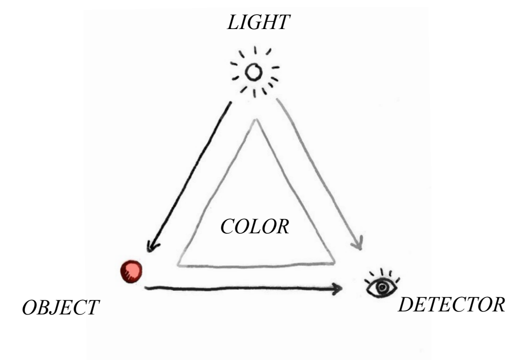
2. Now, turn off the overhead lights and have students examine the spectrum emitted by the red LED lights with the diffraction grating glasses. Ask:

What colors of light do you see? (the diffraction grating shows only RED light is emitted by the red LED)

Why do you think it is easy to identify each crayon under the WHITE overhead lights, but harder to identify some of them under the RED lights?

Accept all answers, and let students know we will continue to explore this question throughout the activity.

3. Turn on the classroom lights again. On the board, draw the color triangle that we introduced in the last activity. Ask students to fill in the three components of the color triangle (LIGHT, OBJECT, DETECTOR), and ask which of these components we explored in the previous investigation (we examined the colors of LIGHT that can be seen by our eyes, a DETECTOR).



4. This time, draw an arrow from the LIGHT source to the OBJECT, and another arrow from the OBJECT to the DETECTOR.

5. Ask students to recap:

What kind of information do our eyes detect? (LIGHT)

If we look at a light source that emits (produces) light, like a light bulb, our eyes detect that light. Now, prompt students to consider:

But how do our eyes detect an object, such as a crayon, that does NOT emit light?

DISCUSSION *continued*

6. Some students will be familiar with the idea that light can be **absorbed** or **reflected** by objects, and may suggest these terms. To engage the whole class, write the words **REFLECT** and **ABSORB** on the board and ask the group to define each term in their own words:

REFLECT means to bend back, or throw back (although students may say "bounce off," as in the light hits an object and bounces off of it)

ABSORB means to take in or soak up (this tends to be a familiar term, as with a sponge)

7. Now direct student attention back to the color triangle and point out the path of light between each component (LIGHT > OBJECT > DETECTOR) as you walk them through the following scenarios with guiding questions:

Say our LIGHT source is white light.

> *What colors of light make up white light?* (all of the colors of the visible spectrum: red, orange, yellow, green, blue, and violet!)

> *What is one tool we can use to observe the colors of light emitted by our light source?* (a diffraction grating to spread them out!)

Because we are using white light, we know all of the colors of light are hitting our OBJECT, which, let's say, is a RED crayon.

> *If we can see a RED crayon, what color of light is being reflected by the RED crayon back to our light DETECTORS (our eyes)*? (RED light!)

So, we know our white light source is emitting all of the colors of light, and all of those colors of light are hitting the crayon, but only the RED light is reflected back to our DETECTORS (which then see a RED crayon)…

> *What is happening to all of the other colors of light that are hitting the crayon, that are NOT being **reflected**?* (they are being **absorbed** by the crayon!)

8. Now, we will change only the color of the object in this scenario. Let's say our OBJECT is now a GREEN crayon.

> *What colors of light are hitting the object?* (all of the colors)

> *What color of light will be reflected by the GREEN crayon for our eyes to detect?* (GREEN light!)

> *What will happen to the RED light, and all the other colors in the white light, when they hit the GREEN crayon?* (they will be **absorbed**)

9. Have students think back to their red light rainbows, and change the color of the light source in the scenario:

Let's say we remove the white light source, and replace it with a light source that emits only RED light, like the one we used for our rainbow drawings. Say our object is once again the RED crayon. Recap:

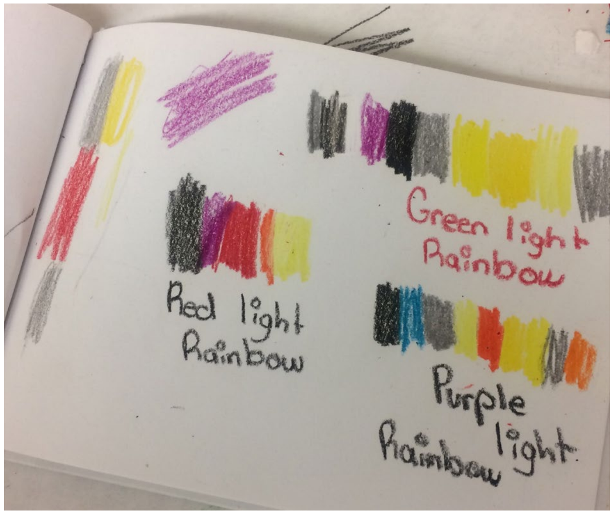
> *Under white light, what colors of light does the RED crayon reflect?* (RED light!)

> *What colors of light does the RED crayon absorb?* (all of the other colors of light!)

Now, when we observe the RED crayon under the RED LIGHT source:

> *What colors of light are **reflected** by the RED crayon back to our DETECTORS?* (still, RED light!)

> *What colors of light are **absorbed** by the RED crayon?* (none, because the RED crayon absorbs all colors *except* RED light, and our light source only emits RED light)



Above, student drawings under different colors of light. The challenge of drawing an accurate ROYGBIV rainbow under a monochrome light source is the result of selective absorption. Monochrome means "one color," and refers to a lightsource that emits a very narrow part of the visible spectrum. While none of the LED lights we use in this activity are true monochrome light sources (they emit some other wavelengths of light in addition to the primary color we see when looking at the bulb) our red LED comes close. When illuminated with red light, the crayons that reflected red light appeared bright, while colors that absorbed red light appeared grey or black. It can be hard to pick the red crayon out of a group that includes white and orange (they all reflect red light), or pick a green crayon out of a group that includes blue and black (they all absorb red light).

DISCUSSION *continued*

Say we switch our object once again back to the GREEN crayon. Recap:

Under white light, what colors of light does the GREEN crayon ***reflect?*** (GREEN light!)

What colors of light does the GREEN crayon ***absorb?*** (all of the other colors of light, except green)

Now consider this GREEN crayon under the RED LIGHT:

Under the RED light, what colors of light are being ***absorbed*** *by the GREEN crayon?* (RED light, because our light source emits only RED light, and the GREEN crayon absorbs all colors of light except GREEN light)

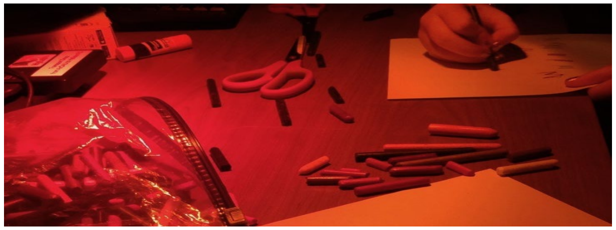
Under the RED light, what colors of light are being ***reflected*** *by the GREEN crayon?* (none: the GREEN crayon reflects GREEN light, but our current light source emits only RED light, which is absorbed, so no light is reflected)

Now consider our experience of color in this scenario. Recap:

What do we call the DETECTORS we use to see colors of the world around us? (our eyes)

What do these eyes actually DETECT? (light)

What do we see if there is no light for our eyes to detect? (darkness)



If our object is a GREEN crayon, which absorbs all of the colors of light except GREEN light, and our light source emits only RED light:

What do we see when we look at the GREEN crayon under RED light? (a dark crayon… the GREEN crayon absorbs all of the RED light, and so there is no light ***reflected*** for our eyes to detect!)

9. Invite students to test this scenario by actually comparing a red and green crayon under different colored lights. Once students have picked out a green crayon and a red crayon and placed them side by side under the lamp at their workstation, prompt them to observe how the colors change when you turn off the overhead lights. The LED lights should still be set on RED.

What did you notice about the color of the crayons when we switched from WHITE light to RED light? (The red crayon still appears red, but the green crayon appears dark and the color is hard to identify)

Ask students to predict what will happen when you switch the LED lights to GREEN light:

Which crayon will appear brightly colored, and which crayon will appear dark?

Use the remote to switch each LED to the GREEN light setting, and ask students to share with their table group observations about how the appearance of the colored crayons changes.

Now ask students how they think the appearance of the crayons will change if the light source is switched to BLUE light.

Will they look the same? Different? Lighter or darker? Try it!

10. Let students know that we are now going to apply this knowledge to a design challenge in which we will experiment further with reflection and absorption, and observe how the the colors of objects we see are affected by the sources of light that illuminate them.

Above, students examine an LED bulb, set to BLUE, using diffraction grating glasses. Students may point out that they can detect more colors under the GREEN and BLUE light than they can under the RED light. Encourage them to think about what this means in terms of **reflection** and **absorption**. If we see more colors when looking at the same rainbow group of crayons under one light source than another, it means that one light source is actually *emitting more colors of light*. When using this LED bulb, we can indeed see more colors under the BLUE and GREEN light settings than the RED. Inside the tri-color bulb there are three light emitting diodes (LEDs): RED, BLUE and GREEN. The RED diode emits a very narrow spectrum that is almost entirely red light, making any object that doesn't reflect red light appear dark. Both the BLUE and GREEN diodes emit much wider spectra but with more intensity in the BLUE and GREEN regions, so more colors of light are reflected back to our eyes.We can observe and compare the emitted spectrum of each diode by looking at the bulb through the diffraction grating glasses as we cycle from the RED to BLUE to GREEN settings.

SET DESIGN FOR COLORED LIGHTS *30 minutes*

1. Ask students if they have ever been in, or seen, a theater production with stage lighting. Ask:

> *What role did the sets and lighting play in the production?*
>
> *How were they used to support the action? Or give the audience clues to the mood of the scene, or the place, or the time of day?*

2. Let students know that they will be working in small groups (3-4) to create a design proposal for an upcoming theater production. This theater has limited storage space and a small crew, so the design team must create one backdrop that can be used throughout the production. To set the mood and context for each scene, the production will be lit with three colored lighting themes: red, green, and blue.

Applying their knowledge of how colored lights affect the appearance of the colored objects (making them appear brighter or darker depending on what colors of light they reflect or absorb) the teams will develop a colored set design that appears to change scenery with each lighting change.

3. Have the design teams decide on an environment, real or imaginary, that they would like to depict with their backdrop (for example: a forest, a city on the moon, an amusement park, a coral reef, etc).

4. Distribute scissors and glue sticks to each student, along with scrap paper to be used as a protective backing while they apply glue to their shapes.

5. Switch the LED lamps back to the RED setting and ask for students to commit again to the behavior agreed upon for safe work in a dim room. Turn off the overhead lights.

Above, students work on their set design compositions under RED light. The areas that appear bright are colors that reflect the most red light, whereas the areas that appear dark absorb most red light.

6. Distribute a sheet of black construction paper to each design group, without identifying the color. Let the design teams know that this piece of paper is a backdrop they will use to develop a small-scale model of their set design on.

7. Now, distribute stacks of construction paper to each design group containing a few sheets each of red, green, and blue paper, without identifying the colors. Under the RED lights, the red construction paper will appear bright, while the blue, green, and black background paper will all appear quite dark.

8. Have the design teams cut out a few shapes from the colored construction paper and arrange them on their backdrop paper to begin to compose a scene. If students point out that they can't tell under the red lights what colors of paper are available to them, remind them that the audience will also be viewing the scene under red light, and encourage them to make choices based on what they see.

They can also begin to make predictions about the colors of paper they are working with. As we change the colors of light, they can collect evidence about which sheets of paper appear brighter or darker under each light source.

9. Encourage students to think about contrast as they cut out and apply shapes to the background paper.

> *Of the paper available for your set design, which can be used to create shapes that contrast with (stand out the most) against the background paper?*

10. When groups are satisfied with the appearance of their composition, they can glue their shapes to the backdrop paper.

11. While students work on their designs, ask them to recall their red-light rainbow drawings.

> *When we turned on the white lights, which colors had we correctly identified?*
>
> *Can we use our knowledge of reflection and absorption to help us identify any of the colors of paper we are working with now?*

12. Once each group has had a chance to cut out and apply some shapes to their background paper under the RED lights, let students know that they are now going to work on the same scene under GREEN light.

Prompt students to think about the crayons, and to recall how the colors that we saw changed when the color of the light source changed.

13. Ask everyone to keep an eye on their composition. Using the remote, change each of the 3 LED bulbs to GREEN.

SET DESIGN FOR COLORED LIGHTS *continued*

Have students identify and share with a partner areas of their designs that changed the most when the light source changed. In their design teams, have students discuss:

> *What parts of the design look different under this color of light?*
>
> *Which areas now appear darker? Lighter? Do the shapes you added still stand out from the background, or do they blend in?*
>
> *Why did the appearance of your design change?*

14. After students have had a chance to cut out new shapes and apply them to their backdrop under the GREEN light, ask them to discuss with their groups:

> *How might this design look different under RED light now that we have added new elements to the composition while working under the GREEN light?*
>
> *What parts might appear brighter if we switch back to RED light? What parts might appear darker?*

15. When everyone is ready, use the remote to switch the lights back to RED, so the students can observe how the colors in their design change and assess their predictions.

16. Turn on the overhead lights. Ask students to consider their designs and share:

> *What colors are you surprised to see? Are there any colors you didn't know you had used?* (perhaps the blue paper)
>
> *Why do you think you couldn't see that color before?*
>
> *Why do you think you CAN see it now?* (white light contains all of the colors)

17. Have the design teams consider what they know about reflection and absorption, and make predictions about what a few specific parts of their composition will look like under BLUE light.

18. Now, have each team cut out at least two shapes for their set design from the BLUE paper, and apply one shape to a part of their design where they think it will appear *brighter* than the surrounding colors and apply the other shape to a part of the set somewhere they think it will appear *darker* than the surrounding colors when illuminated with BLUE light.

19. Have students share their reasoning for their choices within their design teams and then check their predictions by turning the LED lights to BLUE, and turning off the overhead lights.

20. Give students a few more minutes to add anything else to their set design before presenting their proposal to their peers.

Below, the same composition appears quite different as the color of the light source changes. Areas of high contrast that draw the viewer's attention change as the brightness of each colored shape shifts in relation to the colors surrounding it.

DESIGN REVIEW *10 minutes*

1. Have students clear away scrap paper, glue, and scissors from the work stations, and place their designs under the lights for presentation.

2. Ask each group to present their set design, addressing the following:

> *Discuss the color choices you made for each color of lighting.*
>
> *How did those color choices cause the appearance of the set design to change as the lighting changed?*

Have students indicate when they are ready for you to change the LED lamps to the next color using the remote control.

3. As each group presents, encourage the other design teams to provide feedback on what choices work well for creating a variety of moods and focal points in the scene as the light changes and what choices might be reconsidered if they were to refine their design.

30 minute extension: To deepen understanding, students can create a second set design under the white classroom lights, applying their knowledge of how absorption and reflection will cause each color of paper to appear lighter or darker under the different light sources.

COLORS OF NATURE / KIT 4

OPTICS AND ART

How does light help us understand the colors of the world around us?

INVESTIGATION 3 / STRUCTURAL COLOR

GRADES:
4-6

TIME REQUIREMENT
60 minutes minimum. To allow more time for creation and revision of artwork, split this investigation into two class periods. The paper can be made during the first class, accompanied by the discussion of iridescence, followed by a second period in which students use their iridescent paper to create an insect.

Drying time for the paper will depend on heat and humidity of the classroom, and should be taken into consideration when attempting to complete the activity in one class period.

SCIENCE STANDARDS (NGSS)

This investigation can be used in conjunction with other relevant activities towards fulfulling the following performance expectations:

4-PS4-2. Develop a model to describe that light reflecting from objects and entering the eye allows objects to be seen.

MS-PS4-2. Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.

ART STANDARDS (NCCAS)

VA:Cr2.1.4 Explore and invent art-making techniques and approaches.

VA:Cr2.1.5 Experiment and develop skills in multiple art-making techniques and approaches through practice.

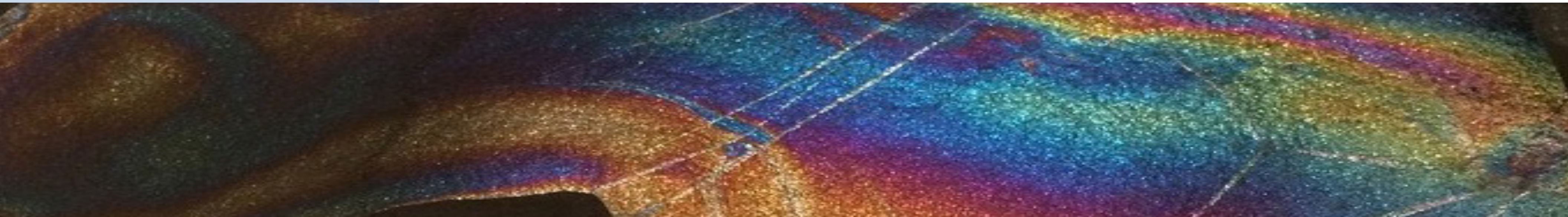
VA:Cr2.1.6 Demonstrate openness in trying new ideas, materials, methods, and approaches in making works of art and design.

OVERVIEW

In this investigation, students explore how a transparent object can produce structural color. Unlike a pigment, which selectively absorbs certain wavelengths of light, these colors are produced when the structure of an object causes wave interference, changing the color and intensity of the light that is reflected to our eye. The result can be shimmering iridescent colors, often seen in plants and animals that rely on eye-catching display colors as part of their strategy to attract mates or pollinators. In this activity, students use thin film interference to make their own structurally-colored paper and apply this material to the design of an iridescent insect sculpture.

LEARNING OBJECTIVES

- *Students will be able to explain that white light is made up of all the colors of the visible spectrum, and can be reflected by objects to our eye, which allows us to see them.*
- *Students will be able to explain how some of the colors we see are the result of the way an object's structure reflects light.*
- *Students will be able to create structurally colored art materials using thin films and apply the results strategically to serve their artistic vision as they create an iridescent insect.*



INVESTIGATION 3 / STRUCTURAL COLOR

How can something clear produce color?

INSTRUCTIONAL APPROACH

This investigation is designed to introduce students to **structural color**, which is produced by the interaction of **light** with the **structure** of an **object.** Many of the colors we see in the world around us are the result of structural color.

To foster engagement and STEAM-linked identities, we advocate for the sharing and discussion of students' own relevant experiences of color and light, and for providing students with opportunities to make choices based on individual preference throughout the activity, so that they are active agents of their own inquiry. The instructor should facilitate student exploration through questions and prompts that encourage:

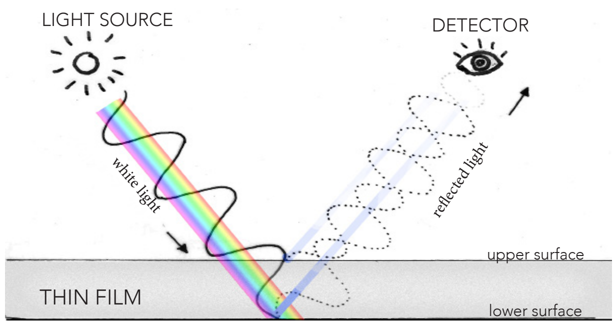
- *sharing examples of experience with structural color from students' own lives*
- *comparison of the qualities of colors produced by structures versus pigments*
- *making connections and identifying similarities between various color-producing structures*
- *experimentation with materials to answer questions as they arise*
- *intentionality in the manipulation of materials in order to serve the artistic vision*
- *articulation of artistic choices*

The instructor should accept all student answers and contributions.

SCIENCE BACKGROUND

In our previous investigation, we explored how the color of an object is often produced by pigments that selectively absorb and reflect specific wavelengths of light.

In today's investigation, we will explore a different phenomenon responsible for the colors we see in the world around us that are *not* the result of light interacting with pigments. Rather, **structural color** is produced by the complex interaction of light waves with the structure of an object. There are many different kinds of structures that can produce color but they all have one thing in common: they occur at a *very small scale*, around the size of wavelengths of visible light (390 to 700 nanometers), or smaller. How small is that? For comparison, consider a human hair which is about 100,000 nanometers. The structures we are talking about are over 100 times smaller than that! These color-producing structures are so small that they are often referred to as nanostructures.

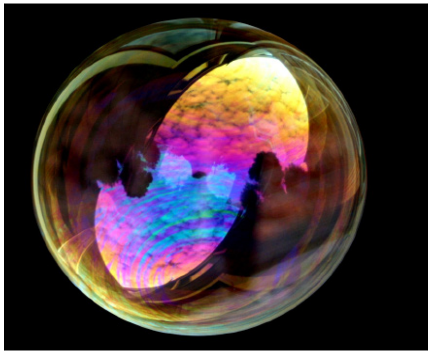


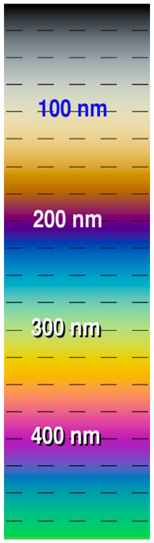
A thin film (above) reflects light from both its upper and lower surfaces. When illuminated by white light, the reflected lightwaves combine in such a way that certain colors of light are enhanced while others are reduced or cancelled out, resulting in the distinct colors we see.

The color produced by these nanostructures is due to **wave interference**, which happens when lightwaves combine in such a way that certain colors are enhanced (constructive interference) or reduced (destructive interference).

Wave interference can result in brilliant colors that appear to change hue or intensity depending on the angle of observation or illumination, causing a glittery effect called **iridescence**. Today we will be exploring one kind of iridescence caused by **thin film interference**. As the term implies, color is produced when a thin transparent film (such as the membrane of a soap bubble) causes **interference** of lightwaves reflecting from both the upper and lower surfaces of the film. The result is that some colors of light are enhanced while other colors are reduced, depending on the thickness of the film.

The distance between the upper and lower surfaces of the film changes how the reflected lightwaves combine, resulting in the enhancement of specific colors. In this sense, the colors we see tell us something about the dimensions of a color-producing structure. Even though the film is so thin that we can't actually see its structure, the colors tell us something about its thickness at any given point, like a rainbow map.





Have you ever noticed how the colors of a soap bubble change as it floats away? The membrane of a soap bubble (above) is a thin film. The colors we see indicate the thickness of the film at any given point. As evaporation and gravity cause the structure of a soap bubble to change over time, we can see the colors shift. This diagram (right) shows the relationship between thickness and color in a soap bubble. Light source, viewing angle, and the refractive properties of the material affect a thin film's color too, so this chart only applies to specific cases.

Photo: Brocken Inaglory, Diaagram: Espiegel123 via Soap Bubble Wiki

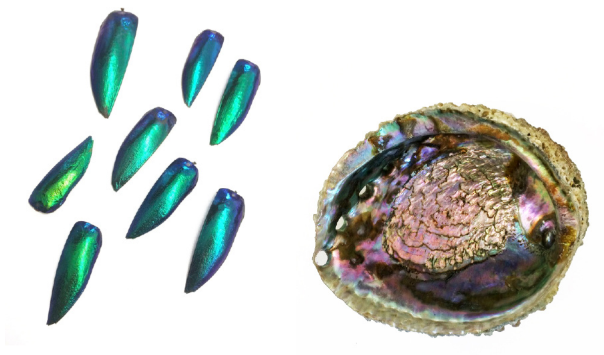
SCIENCE BACKGROUND *continued*

In this investigation, we will make our own **iridescent** material by creating a **thin film** of clear nailpolish and applying it to black paper. The black paper absorbs any light transmitted through the film, making the reflected light caused by **constructive interference** appear intensely colored in contrast.

Structural colors are widely observed in inanimate objects, from the swirling colors on a soap bubble to the rainbow flashes in an opal, but the eye-catching qualities of **iridescence** make it an especially effective **coloration strategy** for many plants and animals whose survival and reproduction depends on the **display** of conspicuous colors to attract pollinators or mates (see *Kit 2: Biology* for activities about coloration strategies).

Photo: Ekaterina Shevstova

Some insect wings, made of thin sheets of transparent chitin, exhibit **thin film interference**. Many species of wasps and flies have stable patterns of **iridescent** colors produced by variations in the thickness of the chitin across their wings. Scientists who study these species only recently discovered the wing patterns because the iridescent colors are nearly invisible unless the transparent wing is observed against a dark backdround. We will see this effect when working with our own **thin films**. Today, we will use examples of these species as reference imagery to inspire and inform the design of our own iridescent insect wing patterns using thin films.



Cultures around the world have long prized the iridescent colors found in nature for art and adornment. The brilliant structural colors of the jewel beetle (above left) and the abalone shell (above right) are caused by nanostructures that result in wave interference.

Japanese artists of the Edo period used iridescent colors intentionally, as in the knife handle (above) where an abalone inlay represents the iridescent colors of a butterfly. The ancient Roman glass artists never planned the rainbows we see on their creations. The iridescent colors we see today is the result of a leaching process that occured when vessels (such as below) were buried in acidic soil, causing the surface to flake into layers of thin films that create wave interference.

Knife handle: The Metropolitan Museum of Art. Roman jar: Toledo Museum of Art.

ART BACKGROUND

In visual art, materials are tools of expression. A major component of the artistic process involves sourcing, selecting, and manipulating materials to serve the aesthetic and conceptual **intentions** of the artist. The nature of visual art means that the **color properties** of a material are often central to its use in the creation of an artwork.

For this reason, the brilliant, sparkling effect of **iridescent color** has been prized for art and adornment. From the shimmering eyes of peacock feathers, to the rainbows of abalone shells and the metallic green of jewel beetles, cultures around the world have collected and treasured iridescent objects for millenia.

Until very recently, artists have had to rely on nature to produce the **structural colors** that dazzle us. Even the characteristic iridescence we see on ancient glass vessels was not an intentional choice by the artists who made them. In fact, they never saw the rainbow colors we see today; they are the result of natural weathering processes that changed the surfaces over time at a molecular scale. The complexity of manufacturing the nanostructures required to create iridescent colors long evaded our technological capabilities. Scientists and artists are still learning how to mimic color-producing structures found in nature.

Today, we will use clear nail polish to intentionally create one of the simplest structures that causes wave interference, a **thin film**, in order to make our own iridescent paper. We will then manipulate this raw material by selecting regions of appropriate colors and patterns from our paper to create sculptural interpretations of the iridescent wing patterns displayed by many insects.

KIT MATERIALS

- **Black 5 x 7" cardstock or 8 x 12" sheets cut in half** *(4 per student)*
- **Clear nail polish** *(1 bottle per group of 3-4 students)*
- **Tupperware bins for water** *(1 bin per group of 3-4 students)*
- **Laminated butterfly wings** *(structural and pigmented)*
- **Butterfly wing micrographs**
- **Iridescent wing pattern cards**
- **Loupes** *(1 per student)*
- **Flashlights** *(1 per 2-3 students)*
- **Thread** *(1-2 spools)*

ADDITIONAL SUPPLIES

- **Dropcloth/protective sheet for drying area** *(about 2 square feet per student)*
- **Scissors** *(1 per student)*
- **Glue sticks** *(1 per student)*
- **Pencils** *(1 per student)*
- **Scrap paper** *(enough to protect tables while gluing)*
- **Construction paper or extra cardstock**
- **Notebooks** *(if applicable)*
- **Clear tape**

Familiar examples of structural color include peacock feathers (magnified, above, right) and soap bubbles (below, right). The iridescent colors of a peacock feather are produced by tiny ridges that act like a diffraction grating, whereas the rainbow colors of a bubble are caused by thin film interference.

SETUP

1. Assemble materials.

2. Fill bins with water, one for every group of 3-4 students. Cut a piece of white paper to fit in the bin for a demo.

3. Identify well-ventilated space for the nail polish activity (outdoors is best, but a large hall or a classroom with plenty of fresh air will work).

4. Create a drying area. Set out a large piece of butcher paper, newspapers, or a drop cloth where students can leave their wet papers to dry. You will need about 1 square foot per student.

HOW CAN SOMETHING CLEAR PRODUCE COLOR?

1. Engage students by asking them if they can think of any colors that are produced by something that is transparent (clear). If students don't have suggestions, prompt them to consider things like the blue of the sky, or the rainbows on a soap bubble. Ask them to speculate:

How can something clear also produce color?

Collect any student answers neutrally, and let them know we will be exploring this question further today.

2. Have the students recap the concepts from our previous investigation, in which we explored **reflection** and **absorption**. Hold up a red object and ask students to explain why it appears red to us (*when illuminated by white light, which contains all of the colors of visible light, the pigments in the red object absorb most of those light waves but reflect the red light waves, which our eyes then detect*).

3. Let students know that today we are going to explore a different way objects can produce color, called **structural color**. Write this term on the board, and prompt students to consider what it might mean:

What is a structure?

If students get at the idea that *structure* refers to the form or shape of something, that is sufficient.

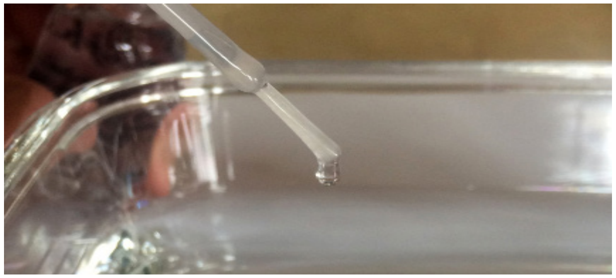
4. One of the structures that can produce color is called a **thin film**. Ask students to describe what they think the shape and size of a **thin film** might be. Let students know that this is the structure we will be exploring today.

NAIL POLISH THIN FILMS *10 minutes*

1. In a well-ventilated space, demonstrate making a **thin film**. Allow a small drop of clear nail polish to fall from the brush onto the surface of a bin of water. Ask students to watch closely and share their observations as you do this:

> *What happens to the drop when it hits the water?* (it rapidly spreads out into a very thin film)

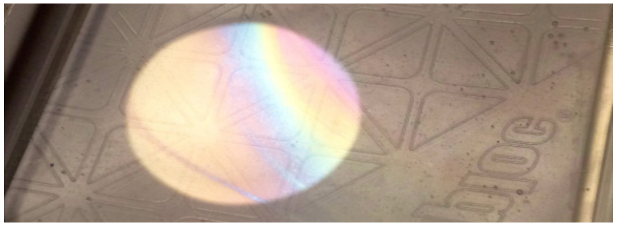
Ask students to move around the bin and look at the film from different angles and to describe anything else they see. They may or may not notice the iridescent colors at this point.



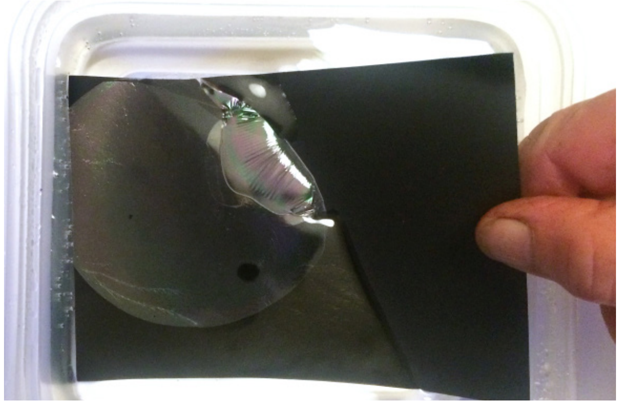
Adding a drop of nail polish to the water (above). When it comes into contact with the water, it will spread across the surface, creating a thin film.

2. Take a small piece of white paper and slide it under the film, lifting it out of the water gently (if lifted too quickly, the film may slide off the paper). Ask students to describe what they see. The iridescent colors may be easier to see when the paper is tilted back and forth.

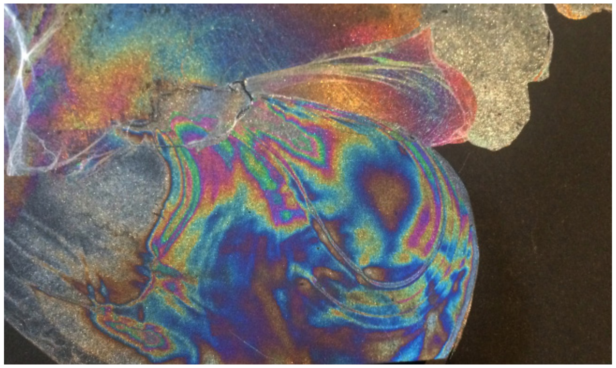
3. Now, write your name in pencil on the back of a piece of black cardstock (and remind everyone they will need to do the same in order to identify their work later). Add another drop of nailpolish to the water and demonstrate sliding the *black* paper under the film and gently lifting it out. The black background of the paper will make the iridescent colors of the film clearly visible (the black pigment in the paper absorbs most of the light, so any light reflected by the iridescent film appears brilliant in contrast).



Clear nail polish spread into a thin film across the surface of a bin of water (above). At certain viewing angles, the iridescent colors may be visible.



Lifting the thin film out of the water by sliding the paper just beneath it (above). The film will adhere best if this is done immediately after the drop of nail polish spreads. The iridescent colors become very visible when the thin film adheres to the black cardstock (below).



4. Ask students to describe their observations of the thin film on the black paper, and connect what they notice to their own prior experience:

> *What do you see?* (a bright marbled rainbow of iridescent colors)
>
> *Have you seen something with colors like this before? What does this remind you of?* (bubbles, gasoline on puddles, etc.)
>
> *What changes as your viewing angle changes?* (it looks brighter or dimmer)

5. Ask students if they know any terms for the kind of color which appears to change when viewed at different angles. Students may be familiar with, and even suggest, the term **iridescence**. Write this on the board. The word comes from the Latin word for rainbow, *iris*, and means “rainbow-colored”.

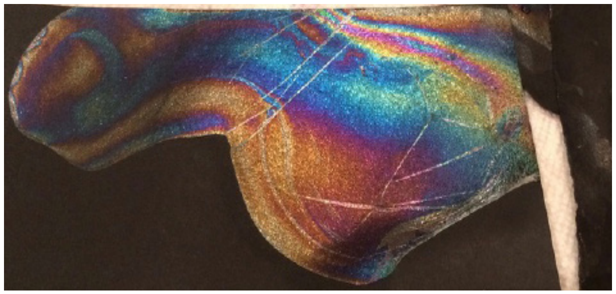
6. Have students observe the nail polish in the bottle:

> *Do you see any iridescent colors in the bottle, or on the drop of nail polish on the brush?*
>
> *What did we have to do to the clear nail polish to produce iridescent colors?* (we changed its structure into a very thin film)

Let students know that the *scale* of a structure plays a critical role in this kind of coloration. The structure, in this case a **thin film**, must be the size of a wavelength of visible light, or smaller, in order to produce colors. By using the water to spread a drop of nail polish into a thin film, we changed the *scale of the structure* we are working with, causing it to produce iridescent colors when illuminated by white light.

NAIL POLISH THIN FILMS *continued*

7. Now, invite students to begin creating their own **iridescent** paper, sharing a water bin in groups of 3-4 students. Remind students to write their name on their paper in pencil so they can identify their work later. When they have lifted off their film, have them set the wet papers in the designated drying zone.



Nail polish thin films on black cardstock, set out to dry (above).

8. As they work, encourage students to share observations or techniques with the group as they are discovered.

9. By listening to student discussions (and exclamations) the instructor can elaborate on ideas or questions that arise and pose them to the group to consider. Questions such as "*would this work on another color of paper... on my fingernail? ...using different colors of nailpolish?*" often come up. Encourage students to answer their own questions by experimenting with materials as available.

The iridescent colors on a DVD (top center), are caused by tiny grooves that encode the digital information. The rainbow of gasoline on a puddle (below) is caused by thin film interference.

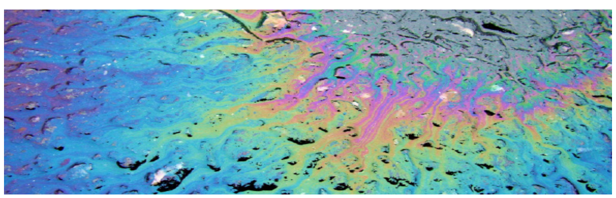


Photo: Sarah Klockars-Clauser via Wikimedia Commons

10. Prompt students to look for underlying patterns in the colors they are observing:

Do you notice anything similar about areas of the film that do not produce color at all? (in thicker areas, or areas where the film folded on itself, it will be clear or white)

Is there anything similar about areas that create gold... purple... another color?

Is there anything similar about the order of colors that appear next to each other?

Can you do anything to control the colors your film makes?

11. Once students have finished making 3 pieces of iridescent paper (or more if time and supplies allow), set them all aside to dry, empty the water bins, clear the tables, and gather the group together for a discussion.

WHAT IS IRIDESCENCE? *15 minutes*

1. Ask students to think again about the colors around them. Now that they have spent some time making colorful thin films with the clear nail polish, have them share other examples of iridescence they have seen, or look for examples in the classroom (e.g. back of CDs or DVDs).

2. Now, pass out the laminated butterfly wings, flashlights, and loupes and have students examine them closely in small groups. Ask students to share observations about the colors of the two butterflies.

What colors do you see?

Besides being different colors, yellow and blue, is there anything else you notice that is different about the qualities of the colors?

The appearance of the iridescent blue wing changes as the angle of illumination and observation changes, whereas the yellow wing (which contains pigments) appears the same from all angles.

3. If the students do not discover this themselves, hold up a laminated set of wings and demonstrate how the angle of illumination affects the pigmented and structural colors differently.

Shine a flashlight on the wings from the front and ask students to identify the colors they see (yellow and blue), and then shine the flashlight through the wings from the back and ask students to identify the colors they see now (yellow and brown). Have students use their flashlights to examine the wings and verify this at their tables.

Why do the colors of one wing change, but not the other?

The yellow butterfly is colored by pigments in the wings that selectively absorb certain wavelengths of light, while reflecting or transmitting others, resulting in the yellow color we see. The blue butterfly has brown pigments in its wings, but a clear nanostructure on one side of the wings causes wave interference in reflected light, resulting in a brilliant blue.

WHAT IS IRIDESCENCE? *continued*

4. Ask students to consider what they know so far about **structural color** (e.g. the material that produces structural color is clear or transparent, the structures are very small, etc.) and ask:

Why might the butterfly wing appear brown when lit from behind, but blue when lit from the front?

Iridescence is the result of a complex optical phenomenon that students are unlikely to be familiar with at this age, but encourage them to share any ideas they have (even if they think they are crazy ideas!) and collect answers neutrally.

5. Show students the printed micrographs of the butterfly wings and ask what they notice about the structures (a pattern of ridges and grooves). Let them know that these structures are made of transparent material, and are so small that they cannot even be seen with a traditional light microscope. Instead, these images are created with a special tool (called a scanning electron microscope) which uses electrons rather than light waves to detect and create an image of the surface of an object. This is why there is no color in these images. Remember, color is light! Ask students:

Where else have you seen a clear structure with tiny grooves or ridges that breaks white light into its component colors?

If students don't suggest it themselves, remind them of the diffraction gratings we used in *Investigation 1: White Light*. Ask students if this gives them any other ideas about how the clear ridges of the butterfly wing might create the blue colors we see when it is illuminated from the front. The goal is to make the connection that the structure of something can interact with white light, separating its colors, as we observed with the diffraction gratings.

Illuminated from the front (above left), this butterfly wing appears a brilliant blue. A clear nanostructure of tiny ridges causes interference in the reflected light, enhancing the intensity of blue light waves and reducing the intensity of other colors through constructive and destructive interference. When illuminated from the back (above right), light passes through the clear ridges and the brown we see is due to the underlying melanin pigments.

6. Have students again recap the components of the color triangle that allow us to see color (**light, object, detector**) and quickly describe how these components interact in order for us to see a pigmented object like a red crayon:

White light, containing all of the colors of light, illuminates the crayon, which contains pigments that selectively absorb some wavelengths but reflect others, in this case red lightwaves, which our eye detects.

7. Let students know that many **structural colors** we see are also produced by **reflected light**, but in a very different way. When white light hits a thin film some light is reflected by the upper surface of the film, some light passes through partially and is reflected by the lower surface of the film, and some light passes entirely through the film.

The size of the structure, in this case the thickness of the film, affects the reflected light, causing some colors of light to appear brighter, and some colors of light to appear dimmer or even disappear. This phenomenon, where light waves affect eachother, is called **interference.**

See *www.colorsofnature.org/structuralcolor* for a video showing the relationship of color and thickness in a soap bubble as it thins from evaporation and gravity.

8. Have students collect their iridescent papers from the drying area and identify the colors they see. Now, ask students to think about what properties of the structure might determine the colors produced:

Why might some areas of the thin film appear iridescent blue, while others appear iridescent yellow?

What might be different about the structure of the thin film in differently colored areas?

Collect all ideas neutrally. We will explore these questions further.

9. Show students the images of fly and wasp wing patterns on a white background. Let students know that scientists only very recently discovered that many flies and wasps have **iridescent wing patterns** specific to each species. Ask students:

What do you think the scientists changed about how they observed these specimens that helped them see the iridescent colors?

Photo: Ekaterina Shevstova

A fly's wings against white and black backgrounds.

WHAT IS IRIDESCENCE? *continued*

10. Now, show the images of the same wings in front of a black background. Ask students:

What changed?

Where have we seen something like this before? (the nail polish thin film on white paper versus black paper)

11. Ask students if they have ever examined the wing of a fly. If time allows, students can look around the classroom or outside for samples! Let students know that the wings of many insects are made of a translucent material called chitin (which is also responsible for the hard exoskeleton of insects as well as the shells and scales of aquatic animals). Ask:

How thick is the wing of a housefly? A fruitfly? A wasp?

These transparent chitin wings are very thin, like our nail polish films, resulting in **iridescent** colors produced by **thin film interference.** By changing the thickness, or the distance between the inner and outer surface of the chitin, the light reflected off each surface interferes differently, determining which colors we see. Ask students to consider:

How might this relate to the colors we see in our iridescent paper? (the nail polish thin film is thicker in some areas and thinner in others)

How do you think the thickness of the film relates to the order of colors we observe next to each other?

Imagine the profile of our thin film. Like a hill, the profile changes height gradually, resulting in a consistent gradient of colors. If the profile was like a city skyline, with sudden height changes, we would see variation in which colors occurred side by side. Students may be able to identify areas on their paper where this occurs due to wrinkles or folds in the film.

12. Knowing what we do from our previous activities exploring **reflection**, **absorption**, and the **electromagnetic spectrum**, ask students to consider:

Why might we be able to see the iridescent colors of our thin films (or the iridescent wing patterns of insects) against a black background… but not so easily on white?

To facilitate this discussion, ask:

What colors of light are reflected by white paper? (all of the colors of light)

What colors of light are reflected by black paper (none, it is absorbing all of the colors of light)

The black paper *absorbs* most of the light that hits it, causing the iridescent colors **reflected** by the **thin film** to appear bright in contrast with the dark background.

When we look at the **thin film** on white paper, which *reflects* most of the light that hits it, there is not much contrast between the light reflected by the thin film and the light reflected by the background. This makes it difficult to see the iridescent colors, similar to how the beam of a flashlight is impossible to see on a sunny day. Considering this, ask students:

Why might the dark brown pigment be useful as a base for the iridescence of the butterfly's wings?

Like the black paper, the dark melanin pigments in the wing provide a light-absorbing base, so the iridescence appears brighter.

Let students know that we will now put our structurally colored materials to use in the design of our own iridescent insect art.

IRIDESCENT INSECTS *20 minutes*

1. Ask students to share their ideas about how artists might use their observations of nature to inspire or inform their work.

2. Let students know that we will be using examples of iridescence from the natural world to inspire our own art as we create a sculpture of an iridescent insect.

3. Pass out the *wing iridescence pattern* cards.

4. Have students choose an example that appeals to them and carefully observe the shapes and colors of the wing patterns. Let students know that their sculpture does not need to be a replica of any specific wing. Rather, they can use the shapes, colors, and patterns they see as a visual reference for designing their own winged insect sculpture.

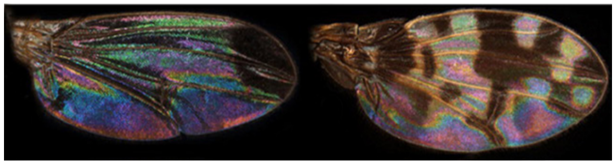
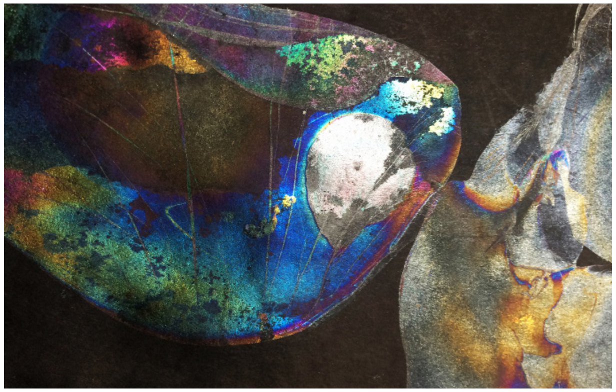


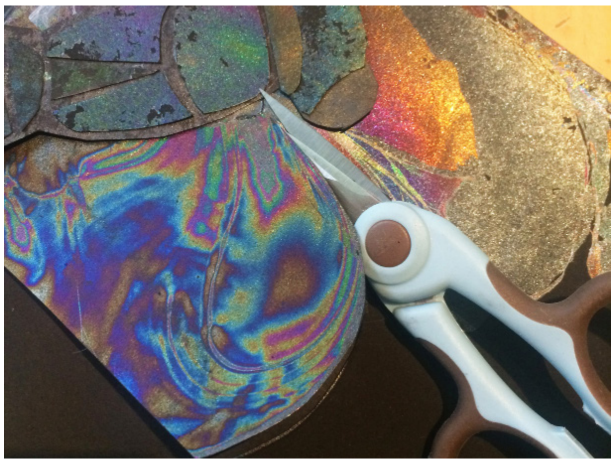
Photo: Ekaterina Shevstova

Examples of iridescent wing patterns (above) can inform student choices about how to srategically cut and assemble their iridescent materials (below) to create an insect.



IRIDESCENT INSECTS *continued*

5. Encourage students to examine their supply of iridescent papers and identify the shapes and colors available to work with. By strategically cutting out shapes from particular areas of their paper, students can intentionally assemble colors and patterns informed by the insect wings they are using for visual reference.



6. Paying close attention to the different colors and shapes on their iridescent papers, students can now cut out useful regions that serve their vision for a winged insect sculpture. Extra black cardstock or construction paper can be used as a base for the wings and insect body onto which students can affix the iridescent shapes using glue or tape.

7. By attaching a piece of thread, the sculptures may be hung for display if desired. Hanging the sculptures has the benefit of allowing them to rotate, highlighting the dynamic colors of the iridescence as the viewing angle changes.

Students can identify and cut out specific parts of their iridescent papers, as shown at left, where the curved patterns in the thin film suggest the shape of a wing. Finished sculptures (above and below) show strategic use of colors and patterns to create visual contrast between different parts of the insects.

SCULPTURE GALLERY *10 minutes*

1. Tidy up the working area and have students hang their finished sculptures (or set them out to display) in a designated space. Gather the group around the gallery and have students present their sculpture by describing and reflecting on their artistic process:

What choices did you make when deciding how to use your iridescent paper to represent an iridescent wing pattern?

How were your choices inspired by the structural colors and patterns you observed in your reference image of iridescent wing patterns?

If you remade this sculpture, what design choices would you make differently next time?

If you made more iridescent paper knowing that you would be making this sculpture, what techniques might you experiment with or what would you change about the process in order to achieve more useful results for your sculpture?

2. Encourage the group to offer constructive feedback to each other, keeping in mind that art appreciation is a subjective experience. What appeals to one person might not appeal to another, but by discussing our personal responses to art, we can begin to understand the range

RESOURCES

Additional teaching resources for this activity are available at:
www.colorsofnature.org/structuralcolor