Lesson Plan: Fading Away

FOR THE TEACHER

Summary
In this lesson students will explore photodegradation of color. First, students will view how fading of paint has affected Van Gogh’s great works of art and the efforts that are being taken to conserve these works. While exploring, students will actively engage in research to relate the fading process to redox reactions, X-Ray diffraction, solute-solvent interactions, and light/energy calculations. Students will then act as an Engineering Task Force and brainstorm to identify how photodegradation affects modern day objects and plan how to address their fading in an effort to market to the airliner Jetstar.

Grade Level
High School

NGSS Alignment
This activity will help prepare your students to meet the performance expectations in the following standards:

- **HS-PS1-4**: Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.
- **HS-PS1-7**: Use mathematical representation to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.
- **HS-PS2-6**: Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
- **HS-PS3-1**: Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
- **HS-ETS1-2**: Design a solution to a complex real-world problem by breaking it down into small, more manageable problems that can be solved through engineering.
- **HS-ETS1-3**: Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

Scientific and Engineering Practices:
- Using Mathematics and Computational Thinking
- Engaging in Argument from Evidence
- Obtaining, Evaluating, and Communicating Information

Objectives
By the end of this lesson, students should be able to

- Use examples from history to identify the main reasons for the degradation of color in paints.
- Predict the charges of atoms before and after a redox reaction.
- Calculate the amount of energy found in portions of the visible light spectrum.
- Hypothesize what components in paint resist the photolytic effect of ultraviolet radiation.

Chemistry Topics
This lesson supports students’ understanding of

- Energy
- Electromagnetic Radiation
- Redox Reactions
• Oxidation Number
• Oxidation
• Reduction
• Bonding
• Molecular Structure
• Intermolecular Forces

**Time**

**Teacher Preparation:** 15-20 minutes

**Lesson:**
• Engage: 10 minutes
• Explore: 10 minutes
• Explain: 45 minutes
• Elaborate: 20 minutes
• Evaluate: 60 minutes (+ 2 week wait period)

**Materials**
• Internet access

**Safety**
• No specific safety precautions need to be observed for this activity.
• If teacher chooses to perform a demonstration during the Explore section, follow the safety guidelines specific to the demonstration.

**Teacher Notes**
• **Engage:** Start by using a Think-Pair-Share Activity. Display the image “Time Machine” from page 6 of the C&EN article. The image compares the faded original van Gogh painting “The Bedroom” to a digitally restored version. The left picture is the *faded* version of the original work of art. The image on the right is the digital reproduction as it probably looked when first painted. The fading in the left picture is caused by degrading of the red pigments used in Van Gogh’s original painting. Possible observations will be:
  o Different red of the bed cover
  o Purple versus blue door and walls
  o The light splotch under the chair that only appears in the left picture
  o Richness of color in the floor in the right picture
• **Think:** Ask students to individually think of answers to the following:
  o WHY do colors fade?
  o Do some colors fade faster than others?
  o What environmental conditions influence pigments in paint to fade?
  o What can be done to prevent colors from fading?
• **Pair:** Students will share their answers with their lab group or person sitting next to them.
• **Share:** Each group will be asked to share their ideas with the rest of the class.

• **Explore:** Show students this SciShow video, “Photodegradation: Why Your Prints Fade When Left in Sunlight.” It is 2 minutes and 16 seconds in length.
• Ask students to answer the following questions again:
  o Why do colors fade?
  o Do some colors fade faster than others?
  Students should deduce red and orange pigments absorb higher frequencies of light. These higher frequencies relate to more energy absorbed to fuel reactions that lead to degradation. The degradation may or may not be of the pigment itself. The binders and additives in the paint
may be what are altered leading to flaking or discoloration.

- Discuss with students the role light plays in this process, but reiterate that other environmental factors can contribute to the fading process.
- The teacher may choose to perform or show a video of a demonstration allowing students to visualize the difference in color observed in metals of different oxidation states: Cr<sup>6+</sup> to Cr<sup>3+</sup>, Fe<sup>2+</sup> to Fe<sup>3+</sup>, Cu<sup>+</sup> to Cu<sup>2+</sup>, Pb<sup>2+</sup> to Pb<sup>4+</sup>, etc. There are also a variety of video clips online to facilitate this viewing without the use of the more dangerous metals. A good example is the reaction that occurs during a Breathalyzer test.

- Students are to read “Van Gogh’s Fading Colors Inspire Scientific Inquiry” from ACS Publication: Chemistry & Engineering News, Volume 94, Issue 5, February 2016. In their lab groups, students are to answer the questions on the student handout “Pay Attention! This will be Faded!” The handout addresses questions generated from the reading, but also requires the student to perform a bit of research to develop a clear understanding of the concepts.

- **Explain:** Discuss the findings with the students. Clarify any misconceptions generated while reading the article and address the energy calculation. An answer key has been provided for teacher reference.

- **Elaborate:** Bring the discussion to modern day paints and surfaces affected by the fading of the paints. Be sure to address the light source of the fading as UV radiation. Ask students to brainstorm techniques companies may take to discourage the fading of paint. Some of these include:
  - Using binders that do not absorb ultraviolet light
  - Using a reflective topcoat
  - Including additives with UV absorbers, drawing the energy from the binder
  - Using a pigment that is absorptive that protects the vehicle
  - Using luminescent pigments which absorb energetic waves and re-emit longer, lower energy waves of light
  - Using UV absorbers similar to sunscreens that absorb high energy UV light and convert it to heat energy; stable form not degraded by UV light.

- Working in groups, students will develop a proposal for the business of Jetstar. The students are to design a proposal focusing on a product that will address fading issues of the paints. Use the “Don’t let Jetstar Fade Away” student sheet. The groups will be guided to make a marketing tool used to sell a self-designed product to Jetstar. This PPG branding suite resource may be helpful for student reference.

- **Evaluate:** The rubric outlines the key elements in the proposal and requires students to make an advertising implement. A brochure, prezi, or webpage are simply ideas—allow students the flexibility to choose the platform.
FOR THE STUDENT

Pay Attention! This will be Faded!

Directions
Answer the following questions while reading “Van Gogh’s Fading Colors Inspire Scientific Inquiry.” You will need to research the answers to many of these questions. Feel free to discuss the answers to each of these questions with members of your lab group. Express your answers in your own words.

1. Artists of Van Gogh’s time struggled with the degrading of color—some even during their lifetime. Which colors did they have issues with?

2. What was the major cause of this loss of color?

3. X-ray fluorescence, as described in the article, identifies the presence of specific elements by exciting electrons using x-rays. When excited, the electron is ejected from an orbital and moved to a higher energy state. The energy is then released by the electron to return back to the ground, unexcited state. The amount of energy released is proportional to the specific element present. X-ray diffraction, however, can be used to identify the compound the element is in. The diffraction pattern of the x-rays off the crystalline structure is compared against a database of known patterns. Scientists, then, can match the unknown compound and identify the chemical species present. What information did this help scientists determine about red lead and why is this useful?

4. In Van Gogh’s “Wheat Stacks under a Cloudy Sky,” red lead (Pb₃O₄ or 2PbO·PbO₂) transformed to two products: Pb(OH)₂ · (PbCO₃)₂ (hydro)cerrusite and PbSO₄ (lead sulfate). An intermediate in this transformation (a compound made in one reaction then used in a different reaction) is plumbonacrite: Pb₅O(CO₃)₃(OH)₂. In order to meet the requirements of the Law of Conservation of Matter, what other elements must have been involved in the reactions of this transformation?

5. In van Gogh’s “Sunflowers”, what yellow pigment is responsible for fading? Write the formula and name for the pigment van Gogh used. What is the oxidation number of the lead ion present? What is the oxidation number of the chromium in the chromate ion?

6. The article makes note of metal ions joining “forces with free radicals generated by oxygen to exacerbate the chromate reduction.” Reduction occurs when electrons are gained. In chromate, the chromium ion will gain electrons. What should happen then, to the charge of the chromium ion?

7. Paints are made of three main components. A pigment—an insoluble substance that colorizes the paint; a solvent—a carrier that allows the paint to flow but generally evaporates once the paint has dried; a binder—a foundation for the paint that sticks around even if the paint has dried; and additives—ingredients to add special qualities to the paint.

The absorption of light excites electrons in the binder. This process is called photolysis. This results in the formation of highly reactive free radicals. A free
radical is a species with an unpaired electron. The free radicals may react with oxygen, water, or other atoms (called autoxidation) in the paint. These reactions will produce MORE free radicals resulting in the attack and cleavage of the binder molecules of the paint. This chain reaction leads to embrittlement. What do you predict to be the overall effect on the paint?

8. According to the article, lead chromate pigments absorb the blue-green light around 490-540 nm. When the light is absorbed, it provides enough energy to release electrons used to reduce the chromium. Calculate the range of energy of light in this blue-green wavelength.

9. If the chromium in the yellow chromate pigments is reduced, what is the charge of the chromium before and after reduction? Indicate the half-reaction of the reduction of the chromium ion.

10. One measure answer museums have implemented to reduce color fading is to use lighting that eliminates the blue-green wavelengths. What is another precautionary measure that you might suggest?

11. As seen in van Gogh’s “Flowers in a Blue Vase”, a conservator attempted to protect the pigments in the painting by varnishing it. A varnish is a resin used as a clear topcoat in order to protect the surface beneath it. Why did the varnish prove to be detrimental to the pigments in the painting?

12. According to the article, how have scientists attempted to solve the problem of chemical degradation?

**FOR THE STUDENT**

**Don’t Let Jetstar Fade Away!**

Now that you are aware of some of the key causes of the fading of a pigment in paint, your group is tasked with the following challenge:

Your group is an engineering task force from PPG. PPG is approached by Jetstar, an Australian airline known for its low cost fares. Jetstar has been informed of your company’s experience with developing paints that do not fade. Fading is a huge issue for the Australian airliner. Their customary color is a bright, vibrant orange.

Jetstar is looking for a coating for its planes that will be durable against the many environmental conditions the planes must endure. On top of that, Jetstar needs a coating that will not weigh the plane down.

In order to obtain the contract with Jetstar, your group must develop a proposal explaining why your product is the answer to their problems. In your proposal, address
the following points:
1. Why is fading an issue for a bright, vibrant orange paint?
2. What chemical reactions can cause the fading and loss of pigment color?
3. How will the issue of fading be addressed while maintaining the integrity of the color and the efficiency of the plane?

Design your proposal to be creative and pleasing to the eye. Looking at the PPG Website for examples of marketing tools used in the past may be helpful!

Your proposal will be assessed by Jetstar using the following rubric:

<table>
<thead>
<tr>
<th>Proposal Element</th>
<th>Excellent (5 points)</th>
<th>Adequate (3 points)</th>
<th>Absent (0 points)</th>
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</thead>
<tbody>
<tr>
<td>Brief explanation of fading.</td>
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<tr>
<td>Focus on the issue of bright orange paint fading (why would orange be more of a problem than other colors?)</td>
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<tr>
<td>Possible reactions that results in paint fading.</td>
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<tr>
<td>PPG’s answer to the problem—proposed solutions to prolong the life of the paint.</td>
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<tr>
<td>Marketing tool highlighting the vibrant orange color (a flyer, Prezi, web page, etc.)</td>
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<tr>
<td>The marketing tool is creative and pleasing to the eye.</td>
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