Resource Details
Date
Mon, 01/06/2020 - 12:00
Region
Arctic
Completion Time
Less than a week
Grade
High school and Up
Permission
Download, Share, and Remix
Location
Toolik Field Station, North Slope, AK
Expeditions
Carbon in the Arctic
Author(s)
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Materials
Heating element: Bunsen burner, hot plate, or sand bath
250-mL beaker
25-mL flask (x4)
100-mL graduated cylinder
Glass stirring rod
Tea bags (x2)
Test tube, 16 x 150 mm in size (x4)
Stoppers, No. 0 (x4)
Aluminum foil square, 10 x 10 inches (x2)
Tape for labeling beakers and tubes
Spectrophotometer cuvette (x5)
Distilled water
Cooler with ice
Cuvette spectrophotometer (Recommended: Vernier Go Direct® SpectroVis® Plus)
Non-dimmable full spectrum LED grow light bulb (Recommended: 65 watt) and housing
Topic
Earth Science
General Earth Science
Tools and Methods
Earth System, Structure, and Processes
Snow and Ice Science
Climate Change

Overview

This activity was prepared by David Walker (LASA High School) and Rose Cory (University of Michigan), based on work conducted during summer 2019 at Toolik Field Station in Alaska. The purpose is to expose students to photooxidation, one of the main pathways by which organic molecules in Arctic streams are oxidized into carbon dioxide. Different teas will be used to symbolize different Arctic streams, colorful due to their dissolved organic carbon content. As Arctic streams are exposed to sunlight during the summer, photoxidation of contained dissolved organic molecules into carbon dioxide results in photobleaching, in which streams slowly lose their color. To mimic this process, students will expose brewed tea to sunlight and analyze for photobleaching using a spectrophotometer.

Background Resources for the Instructor

1. All About Permafrost
2. The Permafrost Positive Feedback Loop
3. Dissolved Organic Carbon
4. Resonance Energy and Color
5. Arctic Oxidation Culprits
6. Sunlight Controls Fate of DOC (Cory, et al., 2014)
7. Carbon in the Arctic (PolarConnect Presentation)
8. Permafrost First-Hand
9. Brewing Permafrost Tea
10. Photoexposure of Permafrost Tea
11. Beer's Law (Chemistry LibreTexts)

Objectives

Students will able able to:

1. Use concepts of molecular orbital theory and electron delocalization to explain why organic compounds exhibit color.
2. Use a spectrophotometer to analyze the visible light absorbance of a given organic sample and determine the wavelength of maximum absorbance (λ_{max}).
3. Prepare a dilution series for an organic sample, plotting solution concentration vs. absorbance at λ_{max}.
4. Use a spectrophotometer to detect photobleaching in an organic sample.
5. Use Beer's law to quantify degree of photobleaching in an organic sample.
6. Explain the relevance of the photoxidation and photobleaching of tea to the photooxidation and photobleaching of dissolved organic carbon in Arctic streams.
7. Explain the relevance of photoxidation and photobleaching to the permafrost positive feedback loop and climate change in the Arctic.

Lesson Preparation

A single group of two students will need the following supplies:

1. Heating element: Bunsen burner, hot plate, or sand bath
2. 250-mL beaker
3. 25-mL flask (x4)
4. 100-mL graduated cylinder
5. Glass stirring rod
6. Tea bags (x2)
7. Test tube, 16 x 150 mm in size (x4)
8. Stoppers, No. 0 (x4)
9. Aluminum foil square, 10 x 10 inches (x2)
10. Tape for labeling beakers and tubes
11. Spectrophotometer cuvette (x5)
12. Distilled water

For the class, the following supplies are needed:

1. Cooler with ice
2. Cuvette spectrophotometer (Recommended: Vernier Go Direct® SpectroVis® Plus)
3. Non-dimmable full spectrum LED grow light bulb (Recommended: 65 watt) and housing

Procedure

1. Prior to lab, purchase a variety of tea bags for students to use (2 needed per group). Good options include black, green, chamomile, and red zinger. The greater variety of color, the better.
2. The below videos should be used as an introduction to the lesson:
    - Photochemistry in the Arctic. This video (from Frontier Scientists) provides an introduction to the photooxidation experiments being conducted by Rose Cory and her colleagues in the Arctic.
    - Midnight Sun in the Arctic. This timelapse video, taken at Toolik Field Station from 8:31 PM to 7:53 AM on June 16, 2019, illustrates the importance of sunlight in the Arctic summer.
    - Brewing and Filtering Permafrost Tea. This video documents the brewing and filtering of a permafrost tea sample at Toolik Field Station during the summer of 2019. This experiment

is directly analogous to the experiment the students will be completing (reference above background information).

- Photoexposure. This video documents the photoexposure of permafrost tea samples at Toolik Field Station during the summer of 2019. This experiment is directly analogous to the experiment the students will be completing (reference above background information).
- Photobleaching of Coke. This timelapse video represents 8.6 days (207 hours) of photoexposure of Coke under a full spectrum LED grow light bulb. Photobleaching is clearly visible, as the Coke slowly turns clear.

3. Brewing of tea (student protocol)
    - In a 250-mL beaker, transfer 150-mL of distilled water.
    - Bring the water to a boil using provided heating element.
    - Remove the beaker from the heating element. Turn the heating element off.
    - Brew a tea solution by immersing 2 tea bags (~4.8 g tea leaves) in the hot water for 5 minutes. Use your glass stirring rod to keep the bags submerged in the solution (take care not to puncture the bags).
    - Remove the tea bags using the attached string, and hold them suspended above the beaker, taking care to let all drops fall into the beaker. After they cool enough to handle, and being careful not to break the bags, squeeze as much solution from the bags as possible into the beaker. Subsequently, discard the used tea bags in the trash bin.
    - Cool your beaker of prepared tea in the ice cooler for 5 minutes.
4. Determine wavelength of maximum absorbance (student protocol)
    - Following the instructions for the provided spectrophotometer, blank the spectrophotometer with a sample of distilled water.
    - Following the instructions for the provided spectrophotometer, analyze a sample of your brewed tea for absorbance in the 400–700 nm range.
    - Prepare a graph of absorbance vs. wavelength for your tea, with wavelength (400-700 nm) on the x-axis and absorbance on the y axis. Using this graph, determine the wavelength of maximum absorbance (λ_{max}). Record this value.
5. Preparation of Dilution Series (student protocol)
    - In the first of your 25-mL flasks, transfer 10-mL of your brewed tea solution. Label this beaker 100%.
    - In the second of your 25-mL flasks, prepare 10-mL of 75% (v/v) tea in distilled water. Label this beaker 75%.
    - In the third of your 25-mL flasks, prepare 10-mL of 50% (v/v) tea in distilled water. Label this beaker 50%.

- In the fourth of your 25-mL flasks, prepare 10-mL of 25% (v/v) tea in distilled water. Label this beaker 25%.
- Following the instructions for the provided spectrophotometer, blank the spectrophotometer with a sample of distilled water.
- Following the instructions for the provided spectrophotometer, analyze each of the above solutions (100%, 75%, 50%, 25%) for absorbance at λ_{max}.
- Using Microsoft Excel® or Google Sheets®, prepare a absorbance vs. concentration curve for your tea by graphing absorbance at λ_{max} vs. solution concentration (100%, 75%, 50%, 25%). Include a point for the distilled water blank (zero absorbance for a 0% solution).
- Determine the equation (y=mx+b) and R2 value for the standard curve. The R2 value should be between 0.95 and 1, indicating an approximately linear relationship (Beer's Law).

6. Preparation of sample tubes (student protocol)
    - Transfer 20-mL of your brewed tea solution into each of the four provided test tubes. Stopper the tubes when finished.
    - Label the tubes as follows: Natural Light Positive, Natural Light Negative, Artificial Light Positive, Artificial Light Negative. Include group members' initials and the date.
    - Wrap the negative control tubes in aluminum foil.
7. Photoexposure (student protocol)
    - Place the natural light tubes (positive and negative) outside in direct sunlight. Leave tubes for 48 hours, minimum.
    - Place the artificial light tubes in the classroom directly underneath the full spectrum grow bulb. Leave tubes for 48 hours, minimum.
8. Analysis for Photobleaching (student protocol)
    - Following the instructions for the provided spectrophotometer, analyze each sample (natural light positive, natural light negative, artificial light positive, artificial light negative).
    - For each sample, prepare a graph of absorbance vs. wavelength, with wavelength (400-700 nm) on the x-axis and absorbance on the y axis. If desired, you may plot all four of these curves on the same graph.
    - For each sample, determine absorbance at λ_{max}.
9. Calculating Extent of Photobleaching (student protocol)
    - Using the equation for your prepared standard curve, use absorbance at λ_{max} to determine the concentration (as a %) of each of your samples: natural light positive, natural light negative, artifical light positive, artificial light negative.

- Take the difference in determined concentration for positive (light-exposed) and negative control (foil-wrapped) samples to determine degree of photobleaching by natural light and artificial light. *Degree of Photobleaching (%) = Negative Control Concentration (%) – Positive Concentration (%)*

10. Have students complete the below assessment tasks and questions in their lab groups.
11. Discuss the assessment questions as a class. Compare results between different lab groups and different types of tea.

Assessment

1. Review these background slides on resonance energy and color. Why do the compounds in tea (and Arctic streams) exhibit color? In your answer, you will need to reference resonance, molecular orbitals, and the HOMO-LUMO gap.
2. Review this background information on Beer's Law. How does your prepared standard curve comparing concentration and absorbance illustrate this law?
3. What are the main differences between natural light (from the sun) and artifical light (from a full spectrum grow bulb)? How are these differences reflected in your data? Cite specific data in your response.
4. Watch this video, featuring scientist Jason Dobkowski (University of Michigan) conducting similar experimentation on the roof of the dry lab at Toolik Field Station. Explain the relevance of the photoxidation and photobleaching of tea to the photoxidation and photobleaching of dissolved organic carbon in Arctic streams.
5. Watch this video on permafrost. Explain the relevance of photoxidation and photobleaching to the permafrost positive feedback loop and climate change in the Arctic.

Extension

This lesson could be extended by having student groups experiment with solutions other than tea (e.g. soft drinks, coffee, juice). Students could also prepare their own version of "permafrost tea" by using water to extract organics from a sample of soil or vegetation and subsequently conduct photoexposure experimentation. Students could also experiment with different lengths of photoexposure.

Transferability

As written, this lab works best in a classroom laboratory environment. For informal educators, it is recommended that students collect different types of vegetation and/or soil to use for the solid-liquid extraction (tea brewing). This makes the lab much more place-based, leading to the following adapted assessment questions:

1. How did λ_{max} change based on vegetation and/or soil type? Attempt to explain these differences.

2. Which types of vegetative and/or soil tea exhibited the greatest degree of photobleaching? Attempt to explain these differences.

Resources

Cory, R. M., et al. “Sunlight Controls Water Column Processing of Carbon in Arctic Fresh Waters.” Science, vol. 345, no. 6199, 2014, pp. 925–928.

Kaplan, L.A., and R.M. Cory. “Dissolved Organic Matter in Stream Ecosystems: Forms, Functions, and Fluxes of Watershed Tea.” Stream Ecosystems in a Changing Environment, 1st ed., Academic Press, 2016, pp. 241–320.

Taterka, Bruce and Rose Cory. “Thawing Permafrost Lessons and Lab Manual: A Multi-Lesson Resource.” PolarTREC, 20 Sept. 2015, www.polartrec.com/resources/lesson/thawing-permafrost-lessons-and-lab-manual-a-multi-lesson-resource.

Ward, Collin P., and Rose M. Cory. “Chemical Composition of Dissolved Organic Matter Draining Permafrost Soils.” Geochimica Et Cosmochimica Acta, vol. 167, 2015, pp. 63–79.

Ward, Collin P., et al. “Photochemical Alteration of Organic Carbon Draining Permafrost Soils Shifts Microbial Metabolic Pathways and Stimulates Respiration.” Nature Communications, vol. 8, no. 1, 2017.

Credits

This activity was created by David Walker (LASA High School) and Rose Cory (University of Michigan), based on work conducted during Summer 2019 at Toolik Field Station in Alaska.

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Standards Other

Next Generation Science Standards (NGSS)

HS-ESS2-2 Earth's Systems

Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.

HS-ESS2-4 Earth's Systems

Use a model to describe how variations in the flow of energy into and out of Earth’s systems result in changes in climate.

HS-PS4-5 Waves and their Applications in Technologies for Information Transfer

Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.