CLIMATE CHANGE TOOLKIT

PPM: The impact of Trace Elements in the Environment

Equipment:

- One-liter clear plastic or glass container
- Liquid food coloring w dropper
- Desk lamp
- Light meter
- Phone or camera to photograph the experiment
- Stirring rod
- Lab coat or similar, and paper towels

Introduction

The US Environmental Protection Agency sets standards for environmental contaminants that can damage human health. Sometimes these threshold levels are very small, expressed as parts per million, or parts per billion. In this experiment we look at the impact of a trace component measured in parts per million - not on human health - but on the way that light interacts with materials.

Why?

Canaries were used in coal mines from the 19th century into the 1980s to protect miners from carbon monoxide poisoning. Canaries are a *sentinel species*, more sensitive to toxic gases than humans, and could thus provide a warning to miners when air quality became hazardous. The current EPA air quality standard for CO is 9 ppm. Human exposure to CO concentrations above150 ppm can be fatal.

Carbon monoxide is just one of many chemicals that can be hazardous to humans and to ecosystems when present even at very low concentrations. A second example comes from the 2014 water crisis in the city of Flint, Michigan, where domestic water supplies in many of homes were found to contain more than 100 parts per billion dissolved lead. The EPA threshold for lead is 15 **ppb**, and its target level is zero. Children are especially at risk; there is no safe level of lead in drinking water.

Despite widespread appreciation of the impact of low concentrations of many environmental contaminants, there is a stubborn skepticism among a segment of our population regarding the impact of 420 ppm CO_2 in Earth's atmosphere. Some individuals ask how a quantity that represents 0.04% of the atmosphere could possibly affect global climate? Yet we see the consequences of ppm and ppb abundances all around us - to the point where canaries accompanied coal miners on the job, every day.

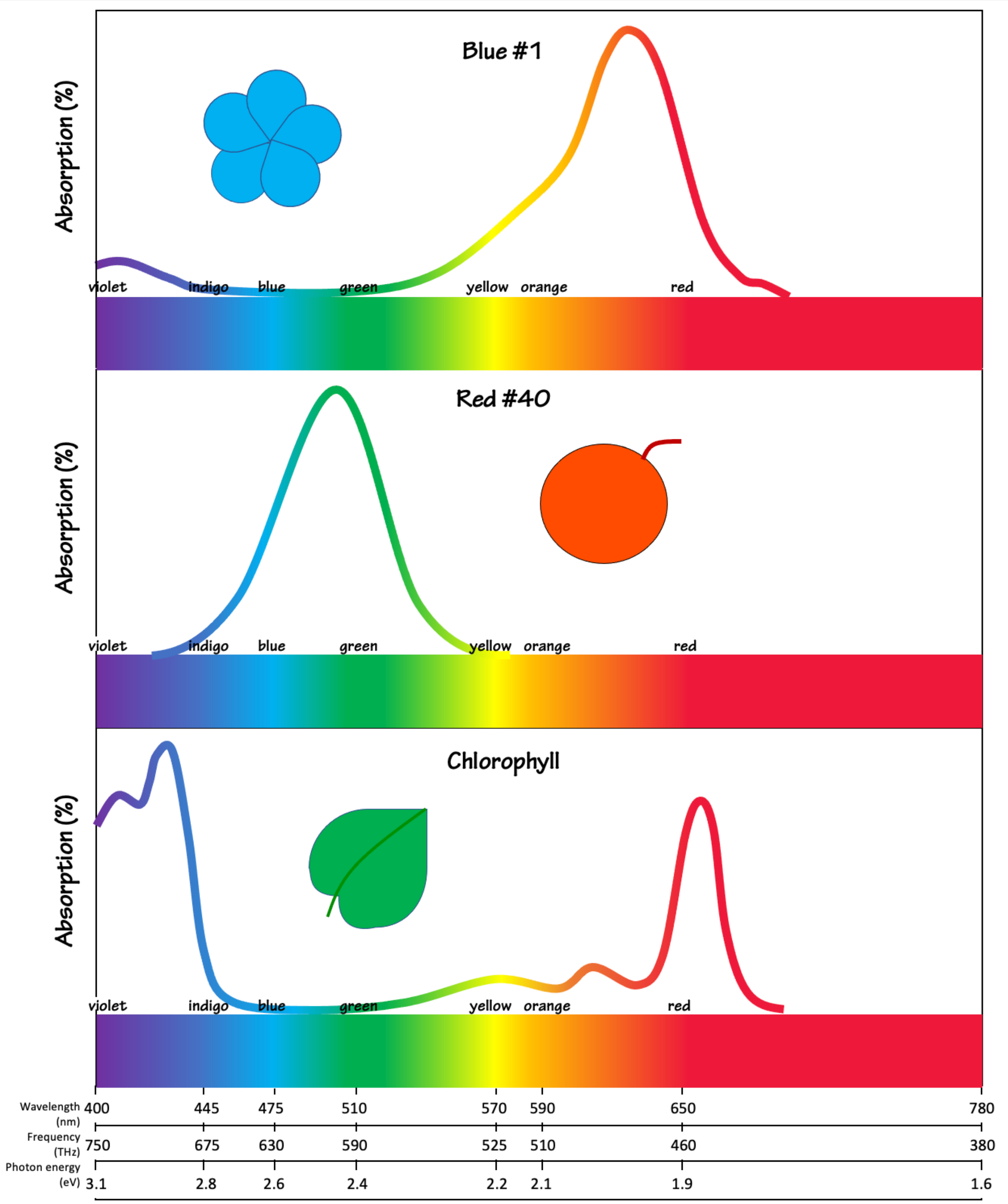


Figure 1: Absorption spectra for three pigments, Blue Dye #1, Red Dye #40, and chlorophyll. Blue #1 absorbs very strongly in the orange and red range of the visible spectrum (peak at 630 nanometers) allowing the blue wavelengths to be transmitted and/or reflected. Red #40 is the opposite, absorbing blue and green wavelengths allowing transmission of red. Chlorophyll is interesting because it has two absorption peaks, at indigo and red, allowing transmission of green wavelengths.

What?

This lab explores the impact of small concentrations. Here we will examine the way light interacts with colored dye in water because it is very similar to the way light interacts with atmospheric gases like carbon dioxide. We can use non-toxic food dyes to visualize changes caused by trace components in water. In this case we will look at the absorption of light as it passes through water samples with varying concentrations of dye.

The pigments used in dyes selectively absorb specific wavelengths of visible light allowing the desired color to be transmitted or reflected (Figure 1). Our eyes detect the transmitted wavelengths as the complementary color to the wavelengths absorbed. The concept of selective absorption is one we interact with every day - probably without thinking about it - because it's the mechanism that produces the colors we see everywhere around us. Selective absorption occurs at other wavelengths beyond the visible spectrum, and the absorption of specific wavelengths in the infrared part of the spectrum is especially important for global climate.

How?

PART 1 – SET UP AND RUN THE EXPERIMENT

- Fill the sample bottle with one liter (1000 ml) of tap water. Let the bottle sit undisturbed for a few minutes, as the action of filling the bottle introduces micro-bubbles to the sample that will affect the transmission of light through the bottle.
- Place the desk lamp on one side of the bottle so that the light shines horizontally through the smooth sides of the bottle.
- Place the light meter on the opposite side of the bottle - on a stand if necessary - so that the light detectors are pointed directly through the bottle toward the desk lamp (Figure 2).

Figure 2: (Above) Experimental set-up with one-liter plastic bottle, desk lamp and light meter. Inset is view from above, after blue dye is added.

- Configure the light meter app to collect data for 5 minutes, using the sensors for white light, blue light, and red light.
- Place a phone or camera in a good spot to take photos of the experiment each time new dye is added

We will run the experiment for five minutes. In the first minute we will leave the bottle undisturbed, with just the tap water, and collect that data as the baseline. Open the dye container so that you're ready to begin adding drops.
Note: be careful when adding the dye and stirring the sample that you don't bump the lamp or the light meter. Your results will not be consistent if the experimental components move around.

- Start the data collection on the light meter app. After one minute, add one drop of dye and gently stir the solution; a few swirls is fine. The color will continue to become more uniform even after you stop stirring.
- Take a photo of the bottle.
- At the two minute mark repeat the process: add a drop of dye, stir, and take a photo.
- Repeat again at minute 3 and minute 4.
- After five minutes stop the experiment, (save data if necessary) close the dye bottle, turn off the lamp.

PART 2 – CALCULATE THE CONCENTRATIONS

The concentration of a mixture can be calculated on the basis of mass or volume. For this experiment the concentration of the solution will be calculated by volume:

$$\text{Concentration (ppmv)} = \text{volume dye (ml)} \div \text{volume water (ml)} * 1\text{x}10^6$$

By convention, one drop of liquid is assumed to have a volume of 0.05 milliliter (ml). Fill in the table below for the dye concentrations at each minute of the experimental run.

Time	**# Drops**	**Concentration (ppmv)**
0 min	0	0
1		
2		
3		
4		

Part 3 – Graph the Results

- Graph your data as a function of time.

This means making graphs with time on the horizontal axis, and your other parameters on the vertical axes. You can make one graph for each parameter (concentration, total illuminance of white light, red light, and blue light) or put them together on a single graph (with vertical axis scales on both on the left and right of the graph). Decide how to best incorporate your photos into your data analysis.

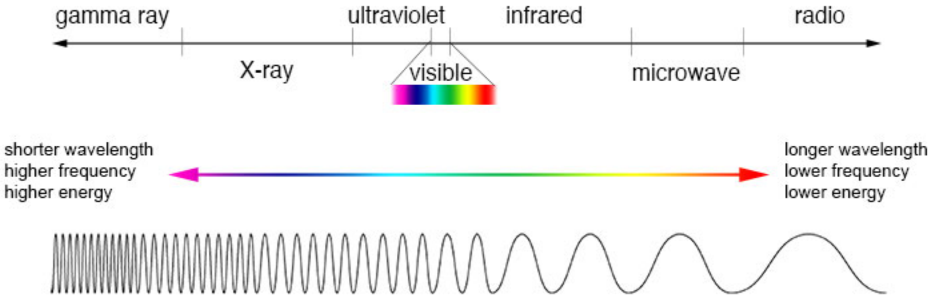
Part 4 – Analysis

In this experiment we applied a disturbance, or forcing factor, to the system that we are studying; we added drops of dye to the bottle of water and observed the result. Since we systematically added increasing amounts of dye, one drop at a time, we should expect to see behavior that changes in a systematic way.

1. Which parameters increased over the course of the experiment?
2. Did any parameters decrease over the course of the experiment? Which?
3. Describe the roles of absorption and transmission in this experiment.
4. Write a short paragraph summarizing your results.

Part 5 - Discussion

In the introduction to this lab we discussed contaminants in the environment, and in particular, we mentioned CO_2 in the atmosphere and its role in climate change. Just like the dye in this lab, CO_2 absorbs light at specific wavelengths. The difference is that CO_2 doesn't absorb visible wavelengths, it absorbs longer wavelengths in the infrared (IR) part of the spectrum.



The wavelengths of ultraviolet and visible light are measured in nanometers (nm = 10^{-9} meters). Longer infrared wavelengths are measured in micrometers (μm = 10^{-6} meters). The blue dye in this experiment absorbs red light at 630 nm. CO_2 absorbs IR light at 4.3 and 15 μm. Figure 3, below, shows the absorbance of CO_2 and chlorophyll (absorbance at 659and 455 nm) together on a logarithmic scale of wavelength.

5. Knowing that CO_2 is present in the atmosphere at a concentration of 420 ppmv, and knowing that CO_2 absorbs IR light at 4.3 and 15 nm, what would you expect to "see" if you had IR-vision that could look at light passing through Earth's atmosphere? Draw, sketch, graph, or describe your ideas.

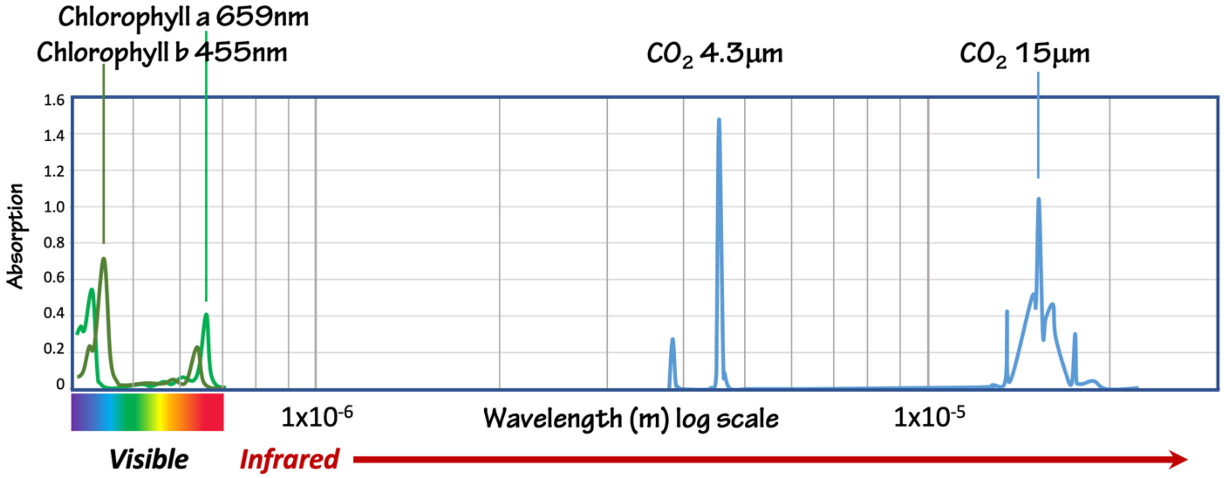


Figure 3: Absorption spectra for chlorophyll and carbon dioxide.