Lesson Plan: Introduction to Color

FOR THE TEACHER

Summary
In this lesson students explore the properties related to color and how those properties vary with changes in concentration. This lesson introduces the use of a spectrophotometer to measure wavelength and absorbance in colored solutions as well as the use of Beer’s Law to determine an unknown concentration.

Grade Level
High School

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

- HS-PS4-4: Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.

AP Chemistry Curriculum Framework
This lesson supports the following unit, topic and learning objective:

- Unit 3: Intermolecular Forces and Properties
  - Topic 3.13: Beer-Lambert Law
    - SAP-8.C: Explain the amount of light absorbed by a solution of molecules or ions in relationship to the concentration, path length, and molar absorptivity.

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

- Contrast hue and intensity as aspects of color and relate them to wave properties.
- Measure wavelength and absorbance spectra of solutions using a spectrophotometer.
- Compare the absorbance spectra of different colored solutions.
- Identify the absorbance spectrum of a mixture as a combination of the spectra of the individual chemicals.
- Complete serial dilutions.
- Compare absorbance spectra of solutions to identify any differences as concentration of the solution changes.
- Create a graph of concentration versus absorbance and apply Beer’s Law to determine the unknown concentration of a solution.

Chemistry Topics
This lesson supports students’ understanding of

- Solutions
- Beer’s Law
- Concentration
- Physical Properties
- Spectrophotometry

Time
Teacher Preparation: 20 minutes

Lesson:
- Engage: 20 minutes
- Explore: 60 minutes
- Explain: 30 minutes
- Elaborate: 20 minutes
- Evaluate: 20-40 minutes

**Materials (per group)**
- Liquid food coloring
- FD&C Food Dyes: Blue #1, Blue #2, Red #3, Red #40, Green #3
- Water
- 10 mL graduated cylinder
- 10 test tubes (at least 10 mL in volume)
- Test tube rack
- Disposable pipets
- Stirring rod
- Vernier SpectroVis or SpectroVis Plus Spectrophotometer
- Cuvettes

**Safety**
- Always wear safety goggles when handling chemicals in the lab.
- Students should wash their hands thoroughly before leaving the lab.
- When students complete the lab, instruct them how to clean up their materials and dispose of any chemicals.
- Do not consume lab solutions, even if they’re otherwise edible products.
- Food in the lab should be considered a chemical not for consumption.

**Teacher Notes**
- **Engage:** Interactive Demo:
  - Hold up containers of different food coloring solutions and ask students to state the color of the solution.
    - Have a few different colors, but have two that would be generally called “blue”. Change the color (not the concentration) so that the two are visibly different blues. This can be accomplished by adding other colors, like red, to the blue, but not going so far as to turn it into another recognizable color.
    - When you get to the 2nd blue, act surprised and say something along the lines of, “But you said this other one was blue and they are clearly not the same color…”
    - Initiate a discussion about how else you might be able to classify colors. Examples are shade, hue, intensity, combining other colors, like green-blue...
  - Hold up the same containers, one at a time. Remind students that the light in the classroom consists of all colors of the rainbow. Ask them which color(s) they think are being absorbed by the solution. You may want to have them record these predictions in a notebook.
    - Next take a sample of one of the solutions and put it into a cuvette. Be sure it is one that will only have one peak. If you are using FD&C dyes, this will be true of any of these. If you are using store-bought food coloring, avoid green. Also, be sure it is dilute enough to give a smooth peak. This should be tested out before class. You will need to show students your computer screen. This is best if you can project it onto a screen or use a SmartBoard to show it.
      - Tell students you are putting the solution into an instrument that will show them which visible colors are being absorbed and which are not.
      - (You should have the SpectroVis already calibrated and ready to go before class.) Insert the cuvette into the chamber and click Collect and then Stop to show the absorbance spectrum of the solution.
• Use the colored background to help students make sense of the plot and how it shows what color ranges are and are not absorbed by the solution.
• Hold up a different color solution and ask them to predict what the spectrum will look like.
• Show them the spectrum of that color and further discuss that the range of colors most absorbed by the solutions are the ones that are NOT seen by the eye.

  o Explain, or reinforce, if this is prior knowledge, that you can only see color because of light. Be sure to clarify the following points in your discussion:
  ▪ Only light in the visible range (ROYGBIV) is perceived by humans as color.
  ▪ If you see a color, it is actually the light that is colored.
• In opaque, colored objects, some light gets absorbed and the rest gets reflected. The light that gets reflected is what reaches our eyes. So, a red piece of paper is red because the colors that get reflected are perceived by our rods and cones as being red. This may be red light or other combinations that blend into red.
• In transparent, colored objects (like solutions), some light gets absorbed and the rest gets transmitted. The light that gets transmitted is what reaches our eyes. So, a blue solution is blue because the colors that do not get absorbed are perceived as blue. This means that light in the range of blue, and possibly some other colors, did NOT get absorbed by the solution.

  o Ask the students to read and underline new ideas from the background.
  ▪ Then discuss the information from the background to ensure they understand that they are going to study some factors that make a color look like it does.

• **Explore:** Students will identify peak wavelengths in the absorbance spectra of different food coloring based solutions. They will also complete a serial dilution of a food coloring solutions to generate data showing how absorbance varies with concentration.
  o **Tip:** You can test the food colorings you are using to determine which will give the best spectra so as to pre-select the one that gives the clearest spectrum for dilution.
  o **Note:** The procedure given is for use with the Vernier SpectroVis Plus or SpectroVis Spectrophotometer, so you may need to alter the instructions if you are using a different type of machine.
  o Skills to review include: how to use a spectrophotometer and any related interface, the safe handling of glassware, how to complete a serial dilution, and how to accurately read a meniscus.
  o Assign each student group a pair of FD&C dyes (two blues or two reds)

• **Explain:** After completing Part A and B, students will be able to identify differences in the wavelengths absorbed in various food coloring solutions and also identify those peaks in a solution made from a mixture of food colorings. After completing Part C students will be able identify that the wavelength doesn’t change, but absorbance does, as the concentration of the solution is decreased through dilution.
  o Skills to review include: how to identify the wavelength of a peak on an absorbance spectrum, how to identify which regions of a spectrum (colors) were absorbed or transmitted to give a solution a certain color, how to construct a scatter-plot graph, how to draw a line of best fit on a graph, how the best fit line describes the relationship between variables.
**Elaborate:**
- Students are asked to consider real-world applications of both using a spectrophotometer for identification of an unknown and for determining the concentration of an unknown solution in the Analysis section.
- Skills to review include: Extrapolation and interpolation of data when using a graph to determine a value for one variable if given the other variable.

**Evaluate:** This activity is structured so that students will demonstrate their findings by recording data as well as evaluating their results through both a graph and questions that support synthesis of the concepts as well as error analysis.
- The conclusion asks them to consider the color of a mixture as being intensive or extensive. They should conclude that the wavelength(s) responsible for the color of the mixture is intensive, but the intensity of the color (concentration of each color-absorbing species) is extensive.

**Preparation of materials:**
- Pure FD&C food dyes may be purchased from any science supply company. They can be purchased as solids or as pre-made solutions, similar in concentration to the food coloring from a grocery store. Blue #2 has a short shelf-life and will eventually degrade and look yellow. Blue #2 can be kept for about a year with success, but it will degrade shortly after that. To avoid accelerated degradation, you should keep this away from light. All other colors are shelf-stable.
- Food coloring may be purchased from the grocery store.
  - Liquid food coloring works better than gel, and red-yellow-green-blue is better than neon colors.
- Food coloring can be used directly from the bottle.
- Food coloring will dye skin and clothing, so have students use gloves if this is an issue.
- Tip: Do a test run first to make sure your initial concentration isn’t too high – absorbance values above 2.0 are much noisier than those at lower values. The reference photo below shows the color intensity that worked well in sample data collection.

**Sample Data and Anticipated Results:**
- **Part A:** Spectra for all four food colorings (red, yellow, green and blue) are shown.
- The line color corresponds to the color of the dye that was used.
- An overall spectrum is included so that you can see how each dye absorbs less in the region of the spectrum that corresponds to the dye color (for example, note the dip in the blue portion of the spectrum found in the analysis of blue dye.)
Part B: Shown below are the individual spectra for yellow, blue and green dyes, shown in the color of the dye used.

- Worth noting is how the spectrum of the green dye includes the peaks found in both the yellow and blue dyes, effectively making it the sum of the blue and yellow dyes.
- The spectrum of the mixture made by mixing blue and yellow together is shown in black.
- Note that the peaks of the mixture match those of the green solution, indicating that the manufacturer likely makes its green dye by combining its yellow and blue.

Part C: Shown below are the spectra for the green dye solution and its first four dilutions.

- Note that as the solution is diluted, the peak wavelength stays the same while the absorbance of that wavelength changes.
- It is possible to see that as the concentration decreases by 50% with each dilution, the absorbance decreases by the same amount.
- Notable is the first dilution, which has as an absorbance in the 2.0 range and therefore is less dependable.
- **Data Section:** Below is the Beer’s law graph for the dilutions above.
- This graph shows the data point that has an absorbance close to 2 but it has not been included in the graph plotted from the data.
- Tip: If student-generated graphs don’t produce a straight line (even after removing high absorbance points), it is likely due inaccurate dilutions.
- Using a volumetric pipet to measure both the solution and the water added will greatly improve the quality of data obtained.

- **Additional Background information:** The following information may be helpful.
- The perceived color of a solution is a function of both the wavelengths absorbed and the amount of absorbing molecules within the solution.
- As the amount of food coloring in the solution increases, the absorbance will increase because there are more molecules to absorb the same amount of light. This will lead to a solution that appears more intense in color. The wavelength best absorbed by the solution, however, remains unchanged as the composition of the solution is the same.
- From this we can see that color must be considered as composed of two different properties: wavelength, which is intensive; and absorbance, which is extensive.
FOR THE STUDENT
Lesson

Is Color Intensive or Extensive?

Background

Modern materials production often involves components from all over the world. Customers still expect product consistency, though, so it is crucial that developers find a way to communicate qualitative ideas such as “color” in a way that can be translated into quantitative values, removing subjective assessment.

Color consistency is important in many different types of products. Paint companies must have a way to quantitatively measure their color mixes to ensure consistency. Drink companies must add just the right amount of each dye to ensure that their drinks are always the same color. Ink producers must ensure the exact ratio of pigments if they are to put out consistent colors for printer inks or for colored pens or markers.

When considering properties such as color, you should recall that some properties are intensive and some properties are extensive. An intensive property is one that does not depend on the amount of substance present. Boiling point is an intensive property. For example, the boiling point of 5 grams of water is 100°C and the boiling point of 1000 grams of water is 100°C. Mass, on the other hand, is an extensive property: a small amount of water has a small mass and a large amount of water has a large mass.

So, what about color? Color is often considered a qualitative and intensive property. 5 grams of sulfur is yellow and 1000 grams of sulfur is yellow. However, color is far more complicated than simply giving it a label, like “yellow”. If the walls in your bedroom are blue and you want to paint over a small section that got scratched off, would you go to the paint store and simply ask for blue paint?

When considering color as a property of a mixture, rather than of a pure substance, there are several factors that contribute to the color we perceive when we look at the mixture. In this exploration, we will consider the simplest type of mixture involving color. Each mixture we study will consist of water, which does not contribute any color to the system, and a single type of molecule that contributes all the color to the system. By varying the type of molecule and the component ratio of the mixture, we can learn more about the simple property we know as “color”.

A spectrophotometer is a useful tool for obtaining quantitative values for colored samples. There are several different types of spectrophotometers for varying uses. The type we are using in this activity can measure values for colored solutions that are transparent. In other words, light must be able to travel through the solution for the instrument to be able to measure the color properties. As we will be using dye molecules in water, we can create solutions that have more water than dye and will, therefore, be transparent.

As you saw in the demonstration, the light absorbed by the molecules in a solution are not the same color as the solution. The spectrophotometer will identify which colors are absorbed and transmitted.
Pre-lab Questions
1. List one intensive property and one extensive property that were not mentioned in the Background or the pre-lab discussion.

2. Which solution is likely absorbing blue light, a red solution or a blue solution?

3. ROYGBIV is a mnemonic to remember the colors of the electromagnetic spectrum (also seen in a rainbow). We have all seen these colors in different varieties. A spectrophotometer measures light according to wavelength. How does wavelength relate to ROYGBIV?

4. Consider the spectrum below.
   a. Which wavelengths have been absorbed the most?
   b. Which were transmitted?
   c. What color would you expect this solution to be?

5. Given the spectra of the two chemicals shown below, sketch what you think the spectrum would be for a mixture of these chemicals. Justify your answer.
Problem
How can color be measured in a quantitative way?

Materials
- FD&C Food Dyes
- Liquid food coloring
- Water
- 10 mL graduated cylinder
- 10 test tubes at least 10 mL in volume
- Disposable pipets
- Stirring rod
- Vernier SpectroVis Spectrophotometer
- Cuvettes

Safety
- Always wear safety goggles when handling chemicals in the lab.
- Wash your hands thoroughly before leaving the lab.
- Follow the teacher’s instructions for cleanup of materials and disposal of chemicals.
- Do not consume lab solutions, even if they’re otherwise edible products.
- Food in the lab should be considered a chemical not for consumption.

Procedure
Part A: Comparing the spectra of different colored solutions

1. Add approximately 8 mL of water to a 10 mL graduated cylinder. Carefully add one drop of the first of your assigned FD&C dyes. Add water using a pipette until it reaches the 10.0 mL mark. Pour it into a test tube. Stir it with a stirring rod as necessary.
2. Repeat Step 1 for each of the following:
   a. The second of your FD&C dyes
   b. The green FD&C dye
   c. Green food coloring
   d. The food coloring that matches your assigned color of FD&C dyes

Note: The following instructions are for use with a Vernier SpectroVis Spectrophotometer.

3. Plug the USB cord from the spectrophotometer into the computer.
4. Open LoggerPro. The spectrophotometer should be automatically recognized and will show a colored rainbow and a blank graph.
5. Calibrate the spectrophotometer by preparing a blank:
   a. Place water into a cuvette.
   b. Holding the cuvette with your fingers on the ridged sides, carefully wipe the smooth sides with a Kimwipe or soft cloth to remove fingerprints, being careful not to scratch it.
   c. Place the cuvette into the spectrophotometer so that the light will pass through the clear sides.
   d. From the Experiment menu, select Calibrate, then Spectrophotometer. Follow the directions in the dialog box to complete the calibration.

6. Empty the water from the cuvette, then prepare it for the next solution: Using a pipet, transfer a small portion of the solution from one of your test tubes into the
cuvette, swirl it around to make sure any droplets of water are removed, then
discard the solution into the sink. Next, transfer another portion from the same
test tube into the cuvette. Clean the clear sides of the cuvette with a Kimwipe and
place it in the spectrophotometer.
7. Click Collect, wait a few seconds to see the plot, then click Stop. Sketch the
spectrum in the data table below. Clearly label the wavelengths of any major peaks.
When finished, empty the cuvette down the sink and rinse it several times with
running water.
8. Repeat steps 6-7 for your remaining solutions. When you click Collect, a dialog box
will appear. Choose “Store Latest Run”. This will store each of your spectra so you
can look back at them, if needed.
9. Complete the Part A Analysis Questions before proceeding to Part B.

Part B: Comparing the spectra of mixtures containing colored solutions

1. Select two different food colorings.
2. Create a water solution for each, as done in Part A.
3. Create a water solution of a mixture of the two, by adding one drop of each and
then diluting to 10 mL, as done in Part A.
4. Using the same procedures as Part A, collect a spectrum for each of these solutions.
5. Sketch each spectrum in the data table below. Clearly label the wavelengths of any
major peaks. When finished, empty the cuvette down the sink and rinse it several
times with running water.
6. Complete the Part B Analysis Questions before proceeding to Part C.

Part C: Comparing the spectra of the same solution at different concentrations

1. Select one color from Part A or Part B that gave you the most distinct peaks. Make
the solution exactly the same way as before (Part A, Step 1). Once it has been
made, transfer it into a test tube, labeled tube “1”.
2. Now you are going to use serial dilution to create several related solutions.
   a. Rinse the graduated cylinder and carefully shake out the water droplets.
   b. Using a pipet, transfer solution from the test tube labelled “1” to the
      graduated cylinder until it reaches 5.0mL.
   c. Pipet water into the graduated cylinder until it reaches 10.0mL.
   d. Carefully mix with a stirring rod.
   e. Pour this into a test tube labeled “1/2”.
3. Repeat Step 2 three times in order to create:
   a. “1/4” solution by combining 5.0 mL of 1/2 and 5.0 mL of water.
   b. “1/8” solution by combining 5.0 mL of 1/4 and 5.0 mL of water.
   c. “1/16” solution by combining 5.0 mL of 1/8 and 5.0 mL of water.
4. Using the same procedure as before, collect a spectrum for each of these solutions.
This time, you will only record the absorbance and the peak wavelength. After
collecting Stop for each spectrum, click Analyze, then Examine. This will bring up a
line that moves with your cursor. Use this to find the wavelength and absorbance
at the highest peak of the spectrum. Record these values in the Part C data table.
5. Answer the Part C Analysis Questions.
### Data

#### Part A: Comparing the spectra of different colored solutions

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<th>Sample</th>
<th>Sketch of the spectrum with peak wavelengths labelled</th>
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**Part A Analysis Questions:**

1. Consider the two different FD&C dyes of the same color.
   a. Would you classify the two solutions by the same ROYGBIV color?
   b. Do the two colors look the same to you?
   c. Compare the spectrum of each of these dyes. Explain how they are different.
   d. How can a spectrophotometer help to quantify the property we know as “color”?

2. The colors in food and drinks may come naturally from the substances in the food and drinks. Often, however, these colors are enhanced with artificial dyes. There are only 7 artificial dyes that are approved to be put into any food or drink product. Each of these seven FD&C food dyes is made from a single type of molecule that absorbs a certain range of light wavelengths. The dyes you used were water solutions of these molecules.
   a. Do the two green solutions look the same to you?
   b. Green food coloring is artificial and, therefore, may only contain the approved dyes. Is the green FD&C dye used in green food coloring? What is your evidence?
   c. Typically, each peak in a spectrum comes from a different light-absorbing species in the mixture. Explain how the entire range of colors seen in sports drinks can be created using only the seven approved dyes.

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**Part B: Comparing the spectrum of a mixture to the spectra of its components**

<table>
<thead>
<tr>
<th>Drops of food coloring (ex: 1 drop yellow + 1 drop blue)</th>
<th>Sketch of the spectrum with peak wavelengths labelled</th>
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**Part B Analysis Questions**

1. Compare the peaks in the mixture to the peaks in the individual colors. How does each part of the mixture contribute to the overall color?

2. Identify the ranges of wavelengths that are absorbed by BOTH of the individual colors.
   a. Find those ranges on the spectrum of the mixture and explain how the absorbance is affected by the presence of both colors.

<table>
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<tr>
<th>Part C: Comparing the peak wavelength of the same solution at different concentrations</th>
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<tr>
<td>Color used:</td>
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<tr>
<td>Concentration of the solution (convert values to decimals)</td>
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<tr>
<td>1</td>
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<tr>
<td>1/2 =</td>
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<td>1/4 =</td>
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<td>1/8 =</td>
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<td>1/16 =</td>
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**Part C Analysis Questions**

1. Review the data collected in the serial dilutions created in Part C.
   a. How did the visible color of the solution change as it became more diluted?

   b. How was the peak wavelength affected by the dilutions? Explain using specific data.

   c. How was the overall spectrum affected by the dilutions? Explain using specific data.
2. Plot a graph of the measured absorbance (y-axis) vs. concentration (x-axis) collected in Part C. Be sure to convert each fraction into a decimal.

3. Consider the graph you created using the dilution data.
   a. Draw a best-fit line for this data.
   b. What kind of relationship is there between concentration and absorbance?
   c. This relationship is referred to as Beer’s law and you can use the best fit line to determine the unknown concentration of a solution. What will be the concentration of a solution that has 1/3 the absorbance of your “1/10” solution?

Error Analysis
1. When using a spectrophotometer, there are several potential errors that need to be avoided. For each of the following, identify what the effect (if any) would be on the absorbance and wavelength and how that would affect the apparent concentration:
   a. Fingerprints on the cuvette
   b. Solution not well mixed
   c. Dust in the solution

Real-World Applications
1. Consider the scenario posed in the Background about painting a small part of your bedroom wall. Paint stores use a different kind of spectrophotometer to analyze paint. Since paint is opaque, the light must be bounced off of it, rather than shone through it. In this case, some light would still get absorbed by the molecules in the paint, but the light that does not get absorbed is reflected. The general method is still the same as that used in this activity.

If you scraped off a sample of paint from your bedroom wall, explain how a spectrophotometer could be used to create a new paint that would perfectly match the paint from your bedroom wall. Use details from this lab to explain your answer.
Conclusion
Write a brief conclusion that reflects on your observations and answers the question, “Is the color of a mixture an intensive or extensive property?”