Adsorption: Dyeing Fabrics with Kool-Aid

https://www.sciencebuddies.org/science-fair-projects/project-ideas/Chem_p106/chemistry/kool-aid-dye-adsorption
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Experimental Procedure

Building Your Spectrophotometer

In this section, you will assemble a circuit on a **breadboard**. If you have never used a breadboard before, you should refer to the Science Buddies reference How to Use a Breadboard (http://www.sciencebuddies.org/science-fair-projects/references/how-to-use-a-breadboard) before you proceed. You can follow a step-by-step slideshow (#) that will show you how to put components in the breadboard one at a time. Alternatively, Table 1 lists each component and its location on the breadboard. **Important**: Read these notes before you proceed.

- Resistors are marked with colored bands. These colors *do* matter. Make sure you pick the right resistors for each step, according to the markings.
- It matters which direction some of the components are facing. Make sure you read the slideshow captions for any special notes about inserting each part.
- This section only shows you how to assemble the circuit. For a detailed explanation of how the circuit works, see the Help (#help) section.

Slideshow with step-by-step instructions viewable online.

Part name	Picture	Breadboard Symbol	Location
9 V battery			Red wire to (+) bus Black wire to (-) bus
Photoresistor			E28, F28
White LED			Long lead to E15 Short lead to F15
Jumper wires (3)			A28 to multimeter J28 to multimeter B15 to (+) bus
220 Ω resistor			H15 to (-) bus

Table 1. Components for the spectrophotometer circuit (Image credits: Jameco and Fritzing).

Testing the Spectrophotometer

After you have finished building your circuit, testing the spectrophotometer is necessary to ensure that all the electronic components are connected correctly and your device works as expected. *Note*: Stray light will cause problems and may result in fluctuating data. Perform the readings in a dimly lit room if stray light is a problem and make sure to always place the cuvettes into your device the same way. It also helps to make sure that the cardboard box is always placed on top of the breadboard the same way, meaning that the same side should be facing toward you at all times.

1. Place one empty cuvette, upside-down, over the LED; and another empty, upside-down cuvette over the photoresistor. If the cuvettes are not clear on all sides but have two grooved or frosted sides, make sure that you put the clear side facing towards the LED as well as the photoresistor. Bend the LED and photoresistor as needed to fit underneath the cuvettes.
2. Place two empty cuvettes between the LED and the photoresistor. Again, make sure that you always face the clear sides of the cuvette towards the LED and the photoresistor. The four cuvettes should touch each other and form a straight line. You can use clear tape to hold the cuvettes over the LED and the photoresistor in place. But do not block the light path!
3. The light from the LED should now shine directly onto the photoresistor, as shown in Figure 6. Bend the wires on the LED and photoresistor for adjustment, if needed.

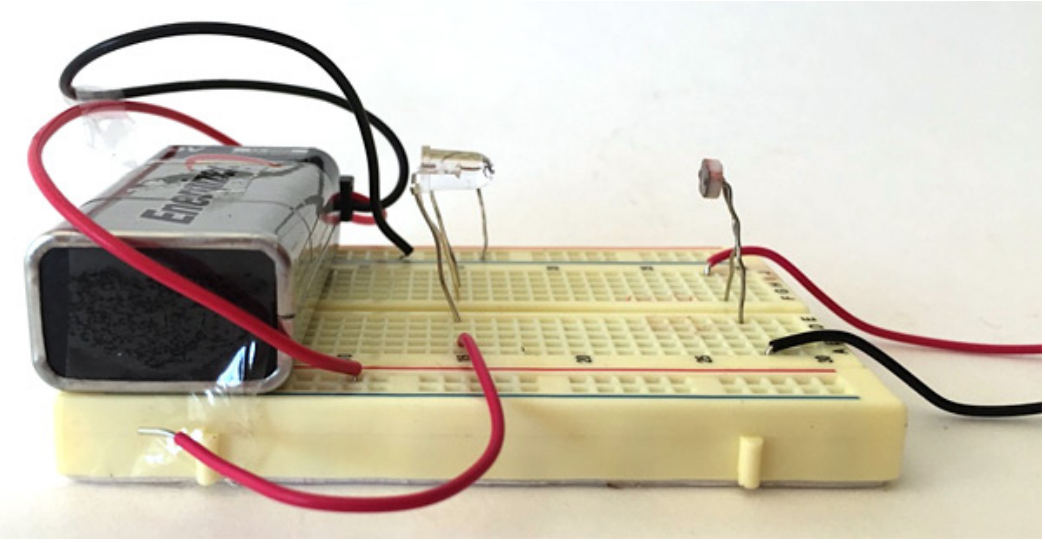

Figure 6. Make sure that the LED and the photoresistor are properly aligned. Note that in this picture, the cuvettes are not placed on top of the photoresistor and LED, yet.

4. Set up the multimeter to measure the resistance of the photoresistor.
    a. Plug the black multimeter probe into the port labeled COM.
    b. Plug the red multimeter probe into the port labeled VΩmA.
    c. Turn the dial setting to 200 ohms (Ω).
    d. Turn the power switch ON.
    e. Use alligator clips to attach the multimeter probes to the jumper wires connected to the photoresistor coming from A28 and J28.
5. Turn on the LED by connecting the jumper wire from B15 to the power (+) bus.
6. Cover the circuit (but not the multimeter) with the cardboard box to block ambient light. Make sure that the same side of the cardboard box is facing you every time.
7. Read the resistance across the photoresistor and record it in your lab notebook.
    a. Note the units of the resistance. A "k" indicates kilo-ohms (kΩ).
    b. If your multimeter screen displays a "1 .", that means the resistance is too high for the dial setting. Turn the dial up to the next highest range (for example, from 200 to 2000) and check again.
    c. If this is your first time using a multimeter, refer to the Science Buddies resource How to Use a Multimeter (http://www.sciencebuddies.org/science-fair-projects/references/how-to-use-a-multimeter), specifically the section How do I Measure Resistance? (http://www.sciencebuddies.org/science-fair-projects/references/how-to-use-a-multimeter#qmultimetermeasureresistance), to learn more.
8. Remove the box and turn off the LED by removing the jumper wire from the power (+) bus.
9. Cover the circuit with the box again. In the dark, the resistance should be in the mega-ohm range. Remember that you may need to adjust the dial setting to get a measurement. Record the resistance in your lab notebook.
10. Remove the box and turn off the multimeter to conserve battery power.

Calibrating the Spectrophotometer

Now that you have set up the spectrophotometer, the next step is to make the **standard** solutions to calibrate it. You will make a series of dilutions of Red 40 dye, with known concentration, as shown in Figure 7, and measure them with your spectrophotometer to create a **calibration curve**. Each dilution is made by consecutively diluting your solution by half. It is essential to use dye-free utensils and cups to get an accurate set of standards.

Figure 7. Standard solutions of Red 40 for calibration of the spectrophotometer.

1. Take eight clean cups and label them #1–8.
2. In the 2 L bottle or bowl, prepare a 4:1 water-vinegar solution by mixing 1600 mL of tap water with 400 mL of distilled white vinegar.
3. Use the measuring cup to pour 400 mL of the water/vinegar mixture into the first cup (#1). Add 200 mL into cups #2–8 each.

4. Add 1 pack (15.6 g) of unsweetened cherry Kool-Aid singles drink mix to cup #1 and stir with a clean spoon until everything is dissolved. *Note*: One pack (15.6 g) of unsweetened cherry Kool-Aid singles drink mix contains 47 mg of Red 40 food dye. This means the Red 40 concentration for standard #1 is about 0.12 mg/mL.
5. Use the measuring cup to pour 200 mL from cup #1 into cup #2 and mix with a clean spoon.
6. Thoroughly rinse the measuring cup and the spoon and mix 200 mL from cup #2 with the water in cup #3.
7. Repeat the two-fold dilutions for cups #4–7. Cup #8 will be your "blank" and should not contain any dye.
8. Label eight clean cuvettes #1–8 (at the very top of the cuvette so you do not block the light path with your writing) and transfer the seven standard solutions and the blank into the matching cuvette using a fresh or rinsed transfer pipette or medical dropper for each one. *Note*: The cuvettes hold approximately 3 mL of solution.
9. Prepare your blue-green absorption filter, by adding 120 mL (or 1/2 cup) of water-vinegar mixture into an extra cup. Add two drops of blue and two drops of green liquid food color dye and mix the solution well with a clean spoon.
10. Transfer the blue-green solution into a clean cuvette and place the cuvette next to the LED so that the clear sides face the LED and the photoresistor..
11. Set the multimeter to read resistance again. Remember that you might have to adjust the range as you take different readings.
12. First, place your blank sample without dye in between the blue-green cuvette and the photoresistor, as shown in Figure 8 on the left. Again, the clear sides of the cuvettes should face towards the LED and the photoresistor.

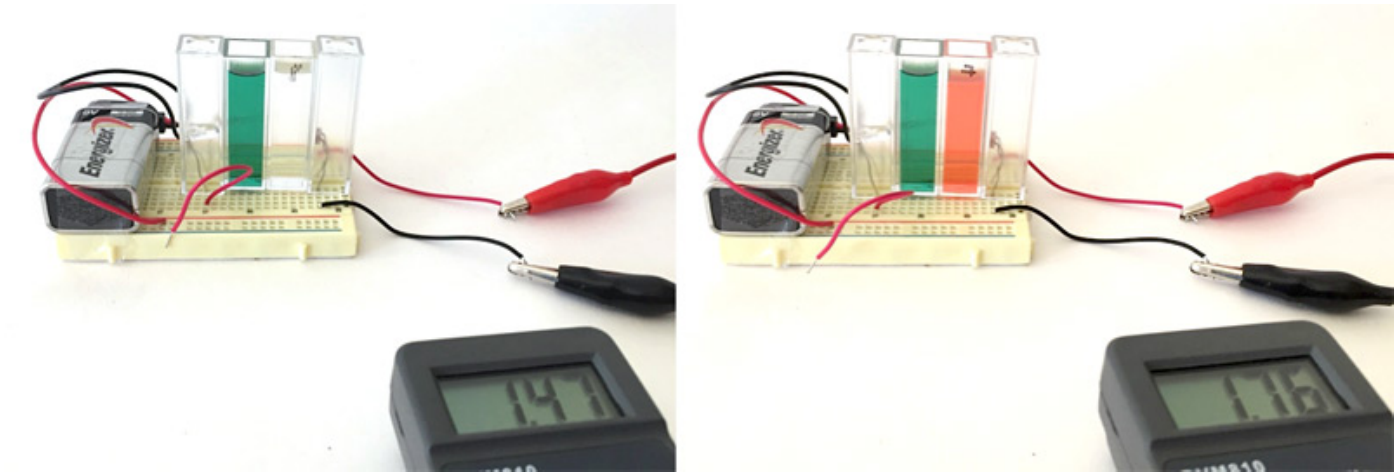

Figure 8. Setup of the spectrophotometer for measuring the blank (left) and standard (right) solutions. Note, that in these pictures, the LED is still switched off and the setup is not covered with a cardboard box yet

13. Plug in the jumper wire from B15 into the power (+) bus to turn on the LED and cover the breadboard with a small cardboard box. Read the resistance on the multimeter and record the data in your lab notebook.
14. Remove the blank cuvette and replace it with the cuvette containing the next standard solution, starting with the lowest concentration. Cover the breadboard again with the cardboard box and write down the resistance for this solution. Continue the measurements for each of your seven standards.
15. Repeat steps 12–14 with the entire set of standards, including the blank, two more times.
16. Make a data table in your lab notebook showing the dilutions and concentrations of Red 40 dye in all your standards (#1 = 0.12 mg/mL, #2 = 0.06 mg/mL, etc.) together with all three recorded resistance measurements for each solution. The resistance should be higher as the solutions get darker.

Starting and Monitoring the Dyeing Process

You will prepare seven different dye bath solutions with different concentrations of Red 40 to compare the concentrations of adsorbed dye and the color of the wool at the adsorption equilibrium.

1. In the 2 L bottle or bowl, prepare more of the water-vinegar solution by mixing 1200 mL of tap water with 300 mL distilled white vinegar.
2. Take seven clean Mason jars and label them #1–7.
3. Use the measuring cup to pour 300 mL of the water-vinegar solution into jar #1, and 150 mL into jars #2–7 each.
4. Add three packs (15.6 g) of unsweetened cherry Kool-Aid singles drink mix to jar #1 and stir with a clean spoon until everything is dissolved.
5. Use the measuring cup to pour 150 mL from jar #1 into jar #2 and mix with a clean spoon.
6. Thoroughly rinse and dry the measuring cup and the spoon and mix 150 mL from jar #2 with the water in jar #3.
7. Repeat the two-fold dilutions for jars #4–7. Discard 150 mL of dye solution from jar #7 so you have 150 mL in each jar. Jars #1–7 will be your different dyeing bath solutions.
8. Transfer about 3 mL of each of these solutions into a fresh (and labeled) cuvette using a fresh or rinsed transfer pipettes for each one, and measure them on the spectrophotometer as you did with the standards before (described starting at step 12 in the section Calibrating the Spectrophotometer (#calibrating)). Make sure to label the cuvettes at the very top and take three measurements for each solution. *Note*: If the resistance of your solution exceeds the maximum resistance of your calibration curve, dilute your sample and measure again. You can do a 1:2 dilution in a fresh cuvette (1.5 mL water-vinegar solution + 1.5 mL dye solution) or a 1:6 (2.5 mL water-vinegar solution + 0.5 mL dye solution). Write down the resistance values for each of your samples in your lab notebook. These values will be your initial dye concentrations at time point 0 (C_0).
9. Cover the top of each jar with aluminum foil to prevent evaporation in the water bath.
10. Fill up an empty pot that fits all seven jars one-third full with tap water and place it on the stovetop to heat the water up until it boils. This will be your water bath to keep your dyeing solutions at a constant temperature. *Note*: While working around boiling water, make sure to

take every precaution to not burn yourself!

11. Once the water boils, place all your dyeing solutions (jars #1–7) into the water bath, as shown in Figure 9. Keep the water bath boiling and let them heat up for about 15 minutes. You might need to keep the burner on a high setting to heat the dyeing solutions up. Pick one jar and monitor the temperature of the solution with a thermometer throughout the experiment. *Note*: If the jars are too large to fit into the pot, you can also transfer all the solutions into smaller Mason jars. Make sure that the jars you choose can tolerate the heat of the boiling water bath.

Figure 9. Put all the dyeing solutions into the boiling water bath on the stove and monitor their temperatures over time.

12. Take the wool felt and cut eight pieces of the same size (about 2.5 cm x 5 cm). If you use wool yarn, cut 8 strings the length of about 26 inches.
13. Weigh each piece or string and record their masses in your lab notebook.
14. Once your dyeing solutions reach about 94–99°C, add one wool felt piece or string to each of the jars. You will keep one for color comparison. Keep track of which one you added (concerning their masses) to which jar. Take a clean spoon and submerge the wool felt or string into the solution to make sure it has good contact with the dye from all sides. Ideally, it should be sitting on the bottom of your jar.
15. Start your timer and set it to 1 h. During that hour, keep the water bath boiling and make sure to monitor the temperature of your dyeing bath solutions (check after half an hour). It should always stay in between 94–99°C. When necessary, add boiling water (from a kettle) to the water bath to increase the water level again.
16. After 1 h take a sample from each dye solution using a clean pipette and transfer it into a labeled and clean cuvette. Measure each sample and the blank sample three times on the spectrophotometer, as described starting at step 12 in the section Calibrating the Spectrophotometer (#calibrating). Write down the measured resistance for each solution in your lab notebook. Remember to do dilutions for each sample that exceeds the resistance values of your calibration curve.
17. Set your timer again to 1 h and repeat sampling and measuring your dyeing solutions and blank every hour until you do not see a change in resistance for each sample anymore. Depending on the wool material you use, this can take between 4–7 hours (see the Materials and Equipment (#materials) section for more details). Make sure to also monitor the temperature of your dyeing solutions every half hour.
18. After about 4–7 hours, all your samples should have reached or should be close to the adsorption equilibrium, which means that their resistance should have reached a plateau. Take all the jars out of the water bath using a towel or oven mitts and inspect the solutions. Write down your observations in the lab notebook. You should notice that all the solutions became less red over time, some even might have become clear, as shown in Figure 10. At the same time, the wool felt or yarn should get more red as it adsorbed more Red 40.

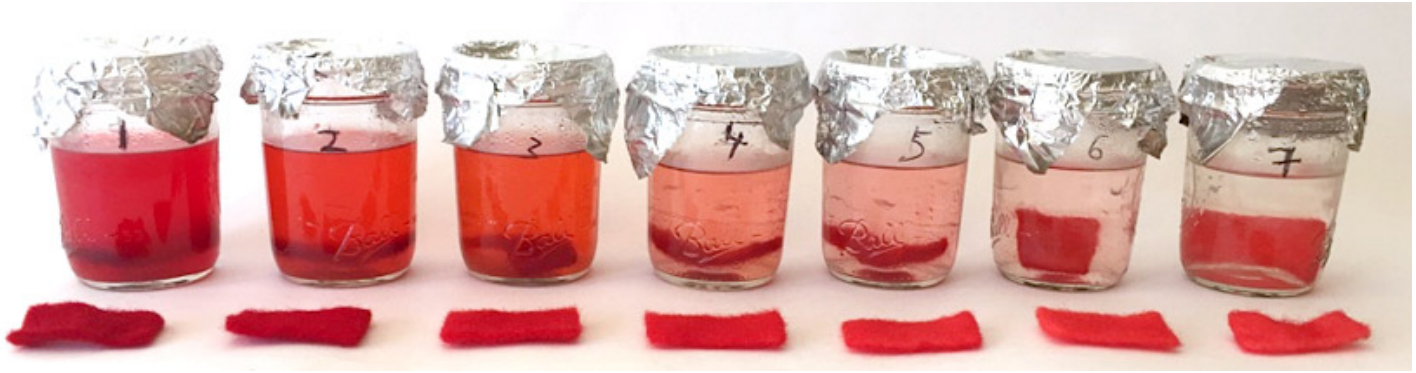

Figure 10. Dyeing solutions at adsorption equilibrium. Note, how some of the solutions became clear and the wool felt turned into different shades of red during the dyeing process.

19. Take the wool felt pieces or strings out of the jars with a spoon—carefully so as not to burn yourself—and rinse them briefly under tap water. Let them dry overnight and assess their color the next day.

Analyzing Your Data

1. Open a computer spreadsheet program, such as Google Sheets or Microsoft Excel, and enter the resistance data for your calibration curve. Calculate the average for your three resistance readings for each sample. Subtract the resistance that you measured for the blank from all of the readings you made for samples with dye. This step subtracts the light loss due to the plastic, the water-vinegar, and other factors.
2. Graph the average resistance of your three readings on the y-axis versus the concentration of the standard solutions in mg/mL on the x-axis.
3. Add a trend line to your data and display its equation and its correlation factor R^2.
4. For each time point, enter your resistance data into the spreadsheet and calculate the average of your three readings for each sample. Again, subtract the resistance that you measured for the blank from all of the readings you made for samples with dye.
5. Using your calibration curve, determine the concentration of Red 40 dye in each of your sample solutions (C_0 and C_t). Remember to account for your dilution factor if a sample had to be diluted.
6. Now, calculate the concentration of dye that has been adsorbed by the wool felt or yarn. You can do that by subtracting the measured concentration of Red 40 in the solution for a given time point from the initial concentration of Red 40 at time point 0 ($C_{adsorbed} = C_0 - C_t$).
7. Make a graph that shows the concentration of adsorbed dye on the wool felt or yarn over time, plotting time (in hours) on the x-axis and the concentration of adsorbed dye (in mg/mL) on the y-axis. How do the graphs look for each dye concentration? Do you see that the adsorbed dye concentrations level off after some time? Once adsorption gets to a plateau, the adsorption equilibrium is reached.
8. From the data of your last time point, or when you reached the adsorption equilibrium, you can determine your adsorption isotherms. To do this, you have to calculate q_e for each of your dye solutions (cup #1–7) according to Equation 3 in the Introduction (#background). Look back into your notes to find the mass of your wool felt pieces or strings (in mg). The volume of your dye bath should be 150 mL.
9. Graph the adsorption isotherm of your dyeing process at about 95°C by plotting C_e, the concentration of Red 40 dye in each jar at equilibrium, on the x-axis (in mg/mL) and q_e for each Red 40 concentration on the y-axis. *Note*: Look in the Bibliography (#bibliography) to find out if your curve follows the expected trend. From where your curve levels off, you can determine the adsorption capacity, or the maximum amount of Red 40 dye that can be adsorbed into the wool felt or yarn.
10. Now you can fit your data to the Langmuir adsorption isotherm model and determine the Langmuir constants Q and b, as shown in the Introduction (#background) in Equation 2. In your spreadsheet, calculate $1/C_e$ (mL/mg dye) and $1/q_e$ (mg wool/mg dye) and plot $1/q_e$ on the y-axis versus $1/C_e$ on the x-axis. You should get a straight line. Add a trend line to your data and display its equation and correlation coefficient R^2. Determine the Langmuir constants Q and b from the intercept and slope of the trend line, with 1/Q being the intercept and 1/(Q b) being the slope.
11. How close is your calculated Q, which indicates the adsorption capacity or the maximum Red 40 that can be adsorbed onto the wool surface, to the experimental value that you determined from your adsorption isotherm graph from step 9?
12. Finally, look at your dried wool felt pieces or strings from each of your dye bath solutions. Do their colors represent the results that you got from your dyeing data? How does the color of the wool felt or yarn that has been dyed with the highest concentration of Red 40 compare to the one with the lowest one? How do you think the knowledge of adsorption isotherms for a given dye/fiber combination is important for dying processes in the textile industry?

Frequently Asked Questions (FAQ)

FAQ for this Project Idea available online at
https://www.sciencebuddies.org/science-fair-projects/project-ideas/Chem_p106/chemistry/kool-aid-dye-adsorption#help.