At-Home Chemistry Experiment

The Rate Law in Chemical Kinetics Using Blue Food Dye

Objective

The objective of this at-home experiment is to demonstrate how the rate law and rate constant can be determined for the reaction of blue food dye with sodium hypochlorite found in bleach, as represented by the following reaction equation:

Blue dye (*aq*) + NaOCl (*aq*) $\rightarrow$ Colourless Products (*aq*)

Introduction

The rate law for a generic chemical reaction,

$$aA + bB \rightarrow \text{products} \quad (1)$$

can be written as

$$R = k[A]^{\alpha}[B]^{\beta} \quad (2)$$

Here,

R = the reaction rate
k = the rate constant
α = the order of the reaction with respect to A
β = the order of the reaction with respect to B
$\alpha + \beta$ = the overall order of the reaction.

The specific rate law for a reaction cannot be predicted; it must be determined experimentally. One technique to do so is to observe the concentration of one of the reactants as a function of time and using integrated rate plots.

In this experiment, the rate of the reaction of NaOCl (sodium hypochlorite), from bleach, with the pigment in blue food colouring is studied. The structure of the dye molecules change due to its reaction with the hypochlorite ion, resulting in the loss of colour. The reaction and its rate law can be represented as follows:

$$\text{Blue dye } (aq) + \text{NaOCl } (aq) \rightarrow \text{Colourless Products } (aq) \quad (3)$$

$$R = k[\text{Blue dye}]^{\alpha}[\text{NaOCl}]^{\beta} \quad (4)$$

where *k* is the rate constant and α and β are the rate orders.

To determine the rate constant, the concentration of the NaOCl (bleach) is varied, but it will also be much larger than the concentration of the blue dye. This way, the change in concentration of the NaOCl during the reaction will be so small that the concentration of NaOCl can be assumed to be constant. This kind of approach is called 'swamping' and will result in a new constant, k_{obs}:

$$k_{obs} = k[\mathrm{NaOCl}]^{\beta} \tag{5}$$

The rate law under swamping conditions can then be simplified to:

$$R = k_{obs}\,[\text{Blue dye}]^{\alpha} \tag{6}$$

The concentration of the blue dye can be measured as a function of time, and integrated rate plots can be used to determine the order of the reaction with respect to the blue dye (exponent α in equations (4) and (6)). The reaction can then be run at a different initial concentration of NaOCl to find the order with respect to NaOCl (exponent β in equations (4) and (5)).

To measure the concentration of the blue dye as the reaction progresses over time, a spectrophotometer in the form of a smartphone will be used. In the experiment, red light will be passed through the blue colored reaction. The red color will come from light reflecting off red construction paper. Since the blue solution can absorb red light, only some of the red light will pass and be detected by the cellphone camera. As long as the solution is dilute enough, the amount of light absorbed will be proportional to the concentration of the absorbing species, as illustrated by the Beer-Lambert law (Beer's Law for short):

$$A = \varepsilon bc \tag{7}$$

where

A = absorbance (unitless)
ε = the extinction coefficient or molar absorptivity ($M^{-1}cm^{-1}$)
b = the pathlength or length of sample through which light from the source travels
c = concentration (M)

Using a color detector smartphone app, which has a RGB feature, the amount of red light passing through the blue solution will be represented by a Red value, R. The amount of red light absorbed by the blue solution is defined as:

$$A = -\log\left(\frac{R}{R_o}\right) \tag{8}$$

where

A = absorbance (unitless)
R = red value from RGB reading; it represents the intensity of red light transmitted through the blue solution
R_o = red value from RGB reading; it represents the intensity of red light transmitted through the solution without the blue dye

Traditionally, concentration values for the absorbing species can be calculated using the Beer-Lambert Law when the extinction coefficient is known (equation 7). However, due to the variability in the extinction coefficient and pathlength for experiments carried out at home, this experiment can only give an approximated rate constant. Therefore, to simplify things, the absorbance values obtained will be assumed to be the concentration values in mol/L (or M). However, analysis of the data using integrated rate plots will still reveal the order of each reactant, thus the rate law for the reaction. A demonstration of how the experimental k_{obs} and k values are determined will also be presented.

Materials

- Water
- Bleach (must have concentration of sodium hypochlorite indicated)**
- Blue food dye*
- ½ cup Measuring cup (125 mL)
- Teaspoon (5 mL)
- Thermometer
- Metal spoon
- Red construction paper
- Standard size (~10 oz) colorless drinking glass used ***only for chemistry experiments***.
- Smartphone
- Glass or ceramic plate
- Timer
- Stand for smartphone (can be a taller drinking glass, preferably colourless)

* Can be from a 'Club House' pack of regular colours, do not use the neon color set.
** Not all household bleach shows the concentration NaOCl on the label. However, some do specify the concentration and it may be in the fine print. See figure 1 below for an example. The bottle should also not be older than ***6 months*** from the time it was first opened. Older bottles will no longer have the same concentration of NaOCl due to decomposition.

<table>
<tr><th colspan="2">WARNING</th></tr>
<tr><td>Bleach

Bleach must be handled carefully.
It may irritate eyes and skin.
Dangerous fumes form when mixed with other products.</td><td>
</td></tr>
<tr><td colspan="2">Do not mix with acid products or household ammonia, rust remover or toilet bowl cleaner. Do not get in eyes. Do not get on skin or clothing. Do not breathe fumes. Keep out of reach of children. In case of spillage, wash your working area and hands immediately. Do not leave bleach unattended.

Wear your lab coat and lab glasses for this experiment.</td></tr>
</table>

Procedure

Part A – Beach dilution 1

1. Download the free app called '*Color Name*' onto your smartphone. Alternatively, you can use any other app that detects color and is able to give an RGB reading.

2. Record the brand name of your bleach and the concentration of the NaOCl onto the data sheet. See Figure 1 as an example.

***Figure 1**: Choose a bleach that indicates the concentration of sodium hypochlorite (NaOCl)l on the label*

3. Place the standard size drinking glass that is colorless in the middle of the red construction paper (make sure you somehow mark this glass so you know it is to be used *only for chemistry experiments and not for drinking!*) Draw a circle around the reaction glass, as well as a mark on the glass in line with a mark on the construction paper (figures 2 and 3). This will allow you to always put the reaction glass in the same position in order to keep the pathlength of the red light readings consistent. If you do not have red construction paper, you may use other red objects (ex. a red shirt or cloth that you would not mind getting damaged if bleach was spilt onto it).

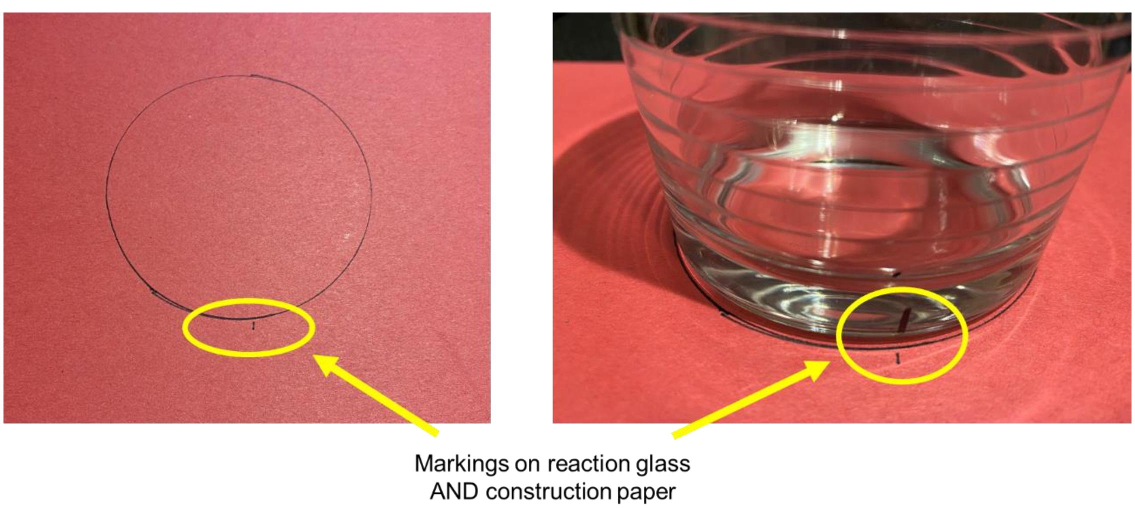

***Figure 2**: Mark the construction paper and glass, and trace out a circle on the red construction paper, to align the glass in the same position for each absorbance reading.*

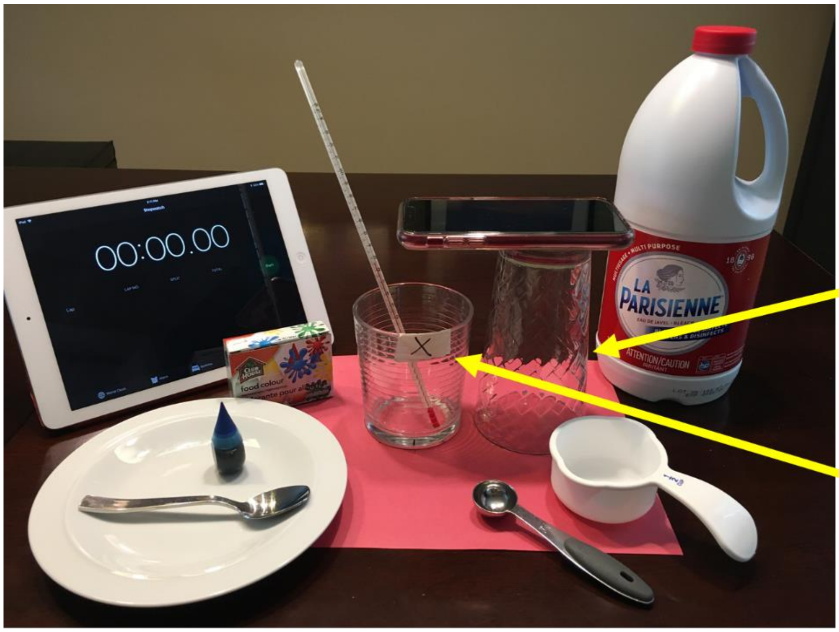

Figure 3: *Materials needed for the experiment. Identify the glass that is intended just for the experiment. A taller drinking glass can be used to elevate the smartphone.*

4. Set up your timer, smartphone and a stand to hold your smartphone as seen in Figure 4. Make sure the bottom of the reaction glass is centered in the camera view.

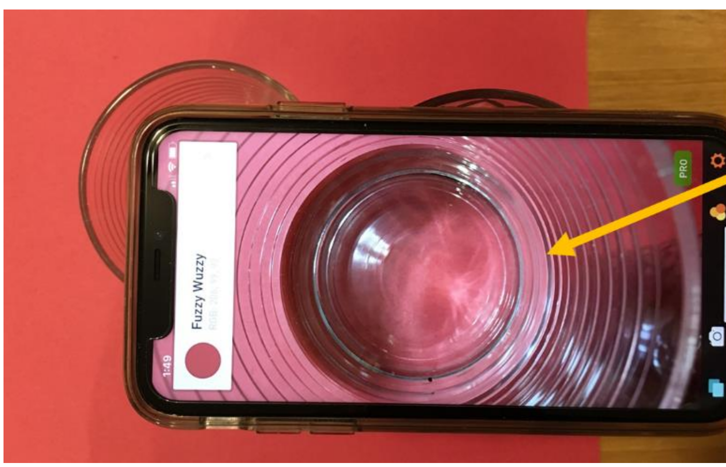

Figure 4: *Positioning of the smartphone camera centered over the glass*

5. Take the reaction glass off the red construction paper. Add ½ cup (125 mL) of room temperature water and ***1 teaspoon*** of bleach (5 mL) into the reaction glass. Stir with a metal spoon to mix the solution. Place the spoon on a glass or ceramic plate. Be careful not to spill the reaction mixture as the bleach can damage clothing, irritate your skin, and damage surfaces.

If the concentration of NaOCl in your bleach is greater than 5%, you will need to use a more dilute mixture for your reaction solution. In a separate container (something that pours well and is *marked for chemistry use only*), add 1 cup (250 mL) of room temperature water and ***1 teaspoon*** of bleach. Stir with a metal spoon to mix the solution. Place the spoon on a glass or ceramic plate. Be careful not to spill the reaction mixture as the bleach can damage clothing, irritate your skin, and damage surfaces. Transfer ½ cup (125 mL) of the diluted bleach solution into the reaction glass. Then proceed with the steps below. Keep the other half of the solution for Trial 2.

6. Measure the temperature of the solution with the thermometer and record it on your data sheet. Rinse the thermometer and place it aside.

7. Make sure the reaction glass is dry, then place it back on the construction paper on the circle, with the marking on the glass in line with the marking on the construction paper. The reaction glass should be centered in the camera view. If not, make adjustments by moving the smartphone and/or stand.

8. Ensure there are ***no shadows*** casted onto the glass during the entire time of the experiment, and the reaction is not directly in any sunlight.

9. Open the '*Color Name'* app on your smartphone. Select 'Live view' and after a few seconds, tap the color identifier box (the white box), and record the first number of the RGB value onto your data sheet. This corresponds to the initial Red value (R_o). It is the amount of red light that is passing through the solution before the blue dye is added. It is being detected by the smartphone camera. See Figures 5 and 6.

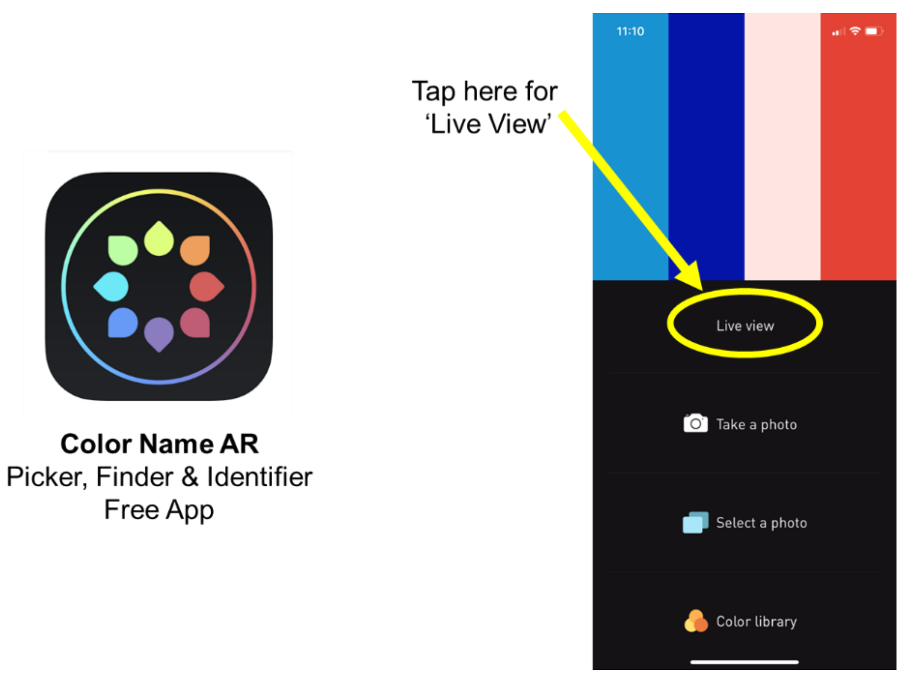

***Figure 5**: Select the 'Live View' within the 'Color Name AR' app*

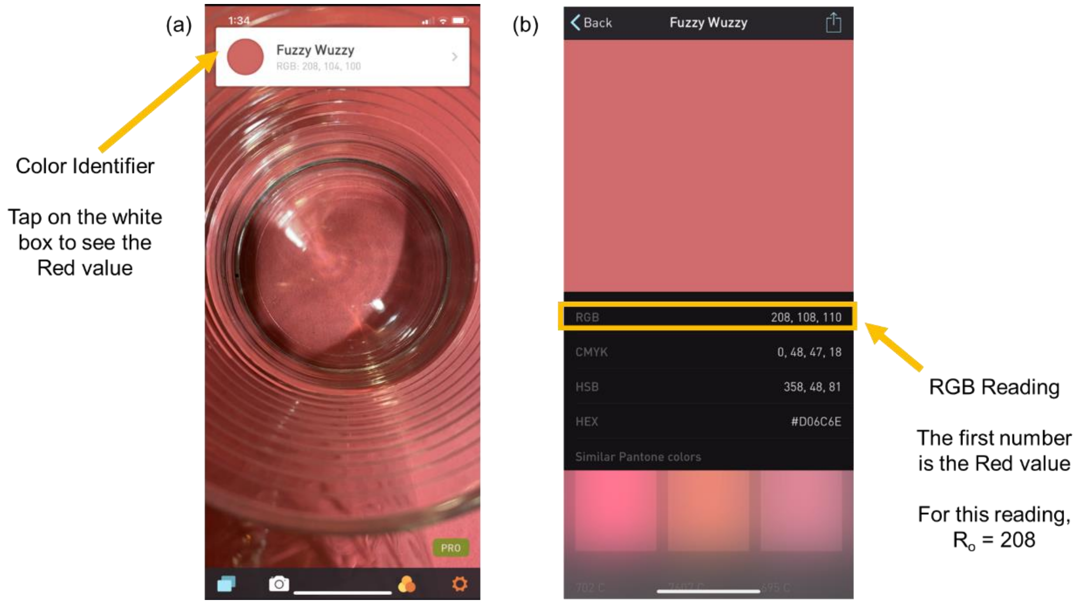

***Figure 6**: The R values are obtained by (a) tapping on the color identifier box and (b) recording the first value from the RGB reading*

10. From this point on, ***do not*** move the smartphone, and do not cast any shadows onto the glass as you observe and record the data. (*Test your hand movements to be sure the smartphone does not move.)*

11. Go back to the live view on the app by tapping on ‘back’.

12. Slide the reaction glass out far enough so that you can add one drop of the blue dye into the glass. **Start the timer** the moment the blue dye is added to the reaction.

13. Quickly mix the solution with the same metal spoon so that it’s homogeneous. Be careful not to spill.

14. Slide the reaction glass back into the circle, lining up the marking on the glass with the marking on the construction paper.

15. At 30 seconds, tap the color identifier box, record the red value on your data sheet, then return back to the live view.

16. Continue recording the red value every 30 seconds until the red color value no longer changes. The solution will be, or close to being, colorless at this point.

17. Leave the smartphone and stand in place, do not move them. Dispose the bleach solution immediately down the drain and rinse the reaction glass with lots of water. Also rinse the teaspoon, metal spoon and the plate holding the spoon.

18. Dry all the equipment, including the thermometer, and repeat the experiment once more (trial 2).

Part B – Beach dilution 2

19. Repeat steps 5 - 18, except use **2 teaspoons** of bleach, and record the R value every 15 seconds. The data will be recorded as trials 3 and 4. Remember to rinse and dry all equipment between each trial, but do not move the smartphone and stand.

20. Take a picture of your experimental set up and include it in your lab report.

Calculations and Data Analysis

For the analysis of the data, use Microsoft Excel to carry out the calculations and to plot the graphs.

1. For each trial:
   a. Prepare the following table of data (each trial should be on separate worksheets):

      i. *Time (s)* - Convert the time readings into total time based on seconds.

      ii. *Absorbance, A* - Calculate the absorbance of red light at each time point using equation (8).

$$A = -\log\left(\frac{R}{R_o}\right)$$

      iii. *Ln A* – Calculate the Ln of each absorbance value

      iv. *1 / A* – Calculate the inverse of each absorbance value

   b. Prepare 3 plots – To determine the order of the reaction with respect to the blue dye, plot the integrated rate plots for zero order, first order and second order reactions. Since we are assuming that absorbance is directly proportional to the concentration of the blue dye, the integrated rate plots can be based on the absorbance as a function of time. Traditionally, the plots would be based on concentration of the absorbing species. However, due to the limitations of this at-home experiment, we will not be able to calculate the concentration of the dye. Provide an appropriate title for each plot and include labels for the axes.

      i. Zero order plot – A vs Time
      ii. First order plot – Ln A vs Time
      iii. Second order plot – 1/A vs Time

c. Determine α for the blue dye - The order of the reaction (α) with respect to the blue dye will be based on the plot that provides a straight line. Exclude data points near the end of the reaction that do not follow the linear trend as the cell phone camera was likely not sensitive enough to capture accurate Red values.
d. Determine k_{obs} – The k_{obs} can be determined from the slope of the most linear plot. This is not a true value of k_{obs} since the concentration of the blue dye is unknown. However, for the purpose of demonstrating this analysis within the limitation of the at-home experiment, we will treat the absorbance as concentration values.

2. Calculate the average k_{obs} based on Trials 1 and 2 (k_{obs}')

3. Calculate the average k_{obs} based on Trials 3 and 4 (k_{obs}'')

4. Calculate the concentration of NaOCl, [NaOCl], (M) – using the concentration of NaOCl provided on the bottle of bleach, calculate the concentration of the NaOCl in molarity (M) in the reaction. Ignore the volume of the blue dye as it's relatively small. The total volume of the solution is based on the volume of bleach and water used. The concentration of bleach on the bottle is expressed as a % NaOCl w/w. Assume this represents the percentage of NaOCl in grams, per 100 g of solution (e.g. 1.5% NaOCl w/w is equivalent to 1.5 g of NaOCl in 100 g of solution). Assume the density of the bleach solution is 1.00 g/mL.

5. Determine β for NaOCl – The order of the reaction (β) with respect to the NaOCl can be determined using k_{obs}', k_{obs}'', the concentrations of NaOCl in part A ([NaOCl-A]) and part B ([NaOCl-B]). Since the rate constant k is the same throughout the experiment, β can be determined using the following equation:

$$\frac{kobs''}{kobs'} = \frac{k\,[NaOCl-B]^{\beta}}{k\,[NaOCl-A]^{\beta}} \tag{9}$$

6. Calculate the value of k using equation (5) for Part A and Part B. Then calculate the average value.

$$k_{obs} = k[\mathrm{NaOCl}]^{\beta} \tag{5}$$

7. Fill in the table in Part C of the data section.

Name ______________________________ Section ______________________________

Date ______________________________

The Rate Law in Chemical Kinetics Using Blue Dye

Data

Brand name of bleach: ______________________________

Concentration of NaOCl in bleach (as indicated on the bottle): ______________________________

<u>Part A – Bleach dilution 1</u>

Trial 1	
Temperature (^oC)	
Initial Red value (bleach + water) R_o	
Reaction Time	**Red Value**
0:30	
1:00	
1:30	

Trial 2	
Temperature (^oC)	
Initial Red value (bleach + water) R_o	
Reaction Time	**Red Value**
0:30	
1:00	
1:30	

Part B – Bleach dilution 2

Trial 3	
Temperature (^oC)	
Initial Red value (bleach + water) R_o	
Reaction Time	**Red Value**
0:30	
0:45	
1:00	

Trial 4	
Temperature (^oC)	
Initial Red value (bleach + water) R_o	
Reaction Time	**Red Value**
0:30	
0:45	
1:00	

Part C – Summary of the data

Value of α (should be a whole number)	Trial 1:	Trial 3:
	Trial 2:	Trial 4:
k_{obs} (s^{-1})	Trial 1:	Trial 3:
	Trial 2:	Trial 4:
k_{obs}' (s^{-1}) (avg k_{obs} from Trials 1 - 2)		
k_{obs}'' (s^{-1}) (avg k_{obs} from Trials 3 - 4)		
[NaOCl] (M)	Part A:	Part B:
Value of β (should be a whole number)	Part A:	Part B:
k	Part A:	Part B:
Average k		
Units for k		
Rate law for the reaction		

References

Department of Chemistry. (2019, Fall). ‘Kinetics of the Bleaching of a Food Dye’, *Chemistry NYB Lab Manual*. Sainte-Anne-de-Bellevue, QC: John Abbott College

Kuntzleman, Tom. “Chemical Kinetics with a Smartphone.” *Chemical Education Xchange*, 27 Nov. 2019, www.chemedx.org/blog/chemical-kinetics-smartphone.

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Reverse Dyeing or How to Tie Dye with Bleach (Optional)

Unlike traditional tie dyeing where you add color to a light-colored fabric, reverse dyeing involves ***removing*** the color that is already in the shirt. The basic wrapping and tying techniques of reverse dyeing or bleach tie dyeing are the same, however you don't need any special tie dye kits. Instead, all you need is a colored t-shirt, hoodie or bedsheet and some plain bleach, water and a spray bottle. The four most common techniques for reverse tie dye are:

- Submerging textile in bleach
- Spraying bleach onto fabric with spray bottle
- Pouring bleach directly on fabric
- Using bleach pen directly on fabric

Materials Needed

- household bleach*
- any textiles (fabric that are 100% natural, like linen or cotton work best)
- small pieces of cardboard, rubber bands, metal clips, etc
- medium size container
- tongs and gloves (for handling the bleached fabric afterward)
- old towel (to put down on the ground outside while working)
- spray bottle

*Disclosure: When using household bleach, you should ALWAYS wear gloves and work in a well ventilated area – like the outdoors.

General procedure

1. Working in a well ventilated area, submerge the fabric in water. Wring out the excess water and fold into different designs.
2. Use cardboard pieces on the front AND back of the folded fabric pieces and use large clips to keep everything in place.
3. Put on gloves and pour bleach directly into a container and make sure there's enough bleach in the container to fully submerged the fabric.
4. Add the folded fabric pieces from step 2 into the bleach and make sure they are fully submerged. Set a timer for anywhere from 5 minutes to 20 minutes. The amount of time the bleach needs to soak into the fabric will vary based on the fabric you're using. But you should be able to see visual change in the fabric color before you remove it from the bleach.
5. With your gloves still on, remove the fabric from the bleach once you're happy with it and rinse it in the sink for several minutes to remove all of the bleach, along with the clips and cardboard pieces. Keep in mind the color will continue to change until the fabric is washed.
6. Wash in the washing machine (no soap needed), then run the fabric through the dryer to heat set before using.

For more information, consult the full reference.

"How to Tie Dye with Bleach: 3 Easy Techniques for Reverse Tie." *Paper and Stitch*, 25 Apr. 2020, www.papernstitchblog.com/shibori-textiles-with-bleach/.