Experiment 13H

THE REACTION OF RED FOOD COLOR WITH BLEACH[1]

PROBLEM:	Determine the rate law for the chemical reaction between FD&C Red Dye #3 and sodium hypochlorite.

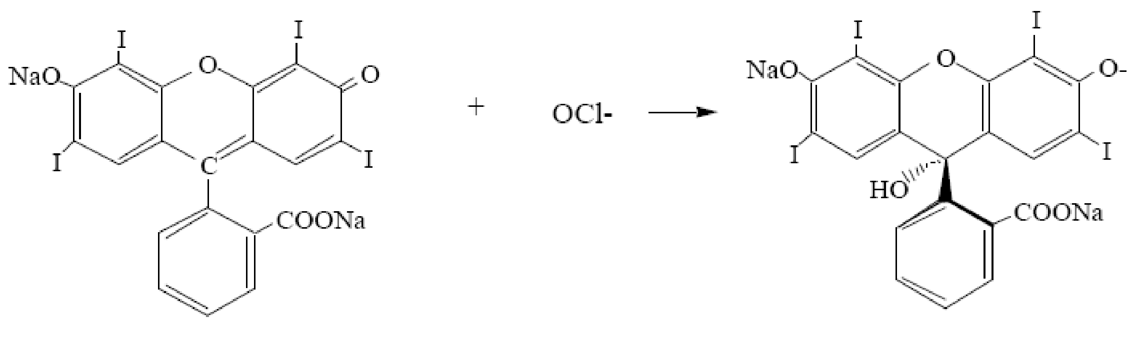
LEARNING OBJECTIVES: By the end of this experiment, the students should be able to demonstrate the following proficiencies.

1. Properly make aqueous solutions, given target volumes and molarities.
2. Relate absorbance measurements to concentrations, using the Beer-Lambert Law.
3. Apply the method of comparing initial reaction rates to determine the order of reaction with respect to reactants.
4. Apply the graphical (integrated rate law) method to determine the order of reaction with respect to one reactant.
5. Control experimental conditions, as needed, to assure proper comparison of rate information

PRE-LAB: Review Appendix I (Spectrophotometry) for a discussion of spectroscopy and application of Beer's Law: https:/www.usna.edu/ChemDept/_files/documents/manual/ApdxI.pdf
Complete the pre-lab questions on page E13H-8 **prior** to coming to lab.

DISCUSSION:

Most people are familiar with the action of bleach on fabrics. If one has done much laundering of clothes, one will recall the warning on the side of a Clorox® bottle against its use on brightly colored clothes. This "bleaching" is a chemical reaction whose kinetics can be easily studied.



Red Dye #3 (red dye) **Hypochlorite Ion** (bleach or OCl^-) **Colorless Product**

[1]Adapted from Henary, M.M., Russell, A.A.*J. Chem. Educ.*, **2007**, 84, 480-482.

The rate of the bleaching reaction is dependent on the concentration of red dye and on the concentration of bleach. This is expressed in the rate law for the reaction:

$$\textbf{rate} = \textbf{k [red dye]}^{a}\,[\textbf{OCl}^{-}]^{b} \qquad (1)$$

Experimental data will allow the values of the orders with respect to each reactant, **a** and **b**, to be determined.

Determination of a: ***Pseudo Rate Law Method (graphical).***

One method for determining reaction orders outlined in general chemistry textbooks involves determining whether a reaction follows certain graphical profiles. However, this method can only be applied if the rate law for the reaction involves only one reactant. This may appear rather limiting, since most chemical reactions involve at least two reactants. As shown below, however, there is a way, in principle, to cause a reaction involving multiple reactants to appear to include the change in only one reactant. This method is known as the Pseudo Rate Law Method. By running the bleaching reaction with a large excess of bleach, OCl^- , the $\Delta[OCl^-]$ will be approximately equal to zero, therefore, $k' = k[OCl^-]$ and the rate law simplifies to: rate = $k'[\text{red dye}]^a$ and the rate of reaction leads directly to the order with respect to red dye, **a**.

Determination of b: ***Method of Initial Rates.***

The Method of Initial Rates for determining orders of reaction is illustrated in your textbook. This method simply involves a comparison of two different trials, the only difference between the trials being the concentration of one of the reactant species. The value of **b** in this experiment will be found by this method through holding the concentration of red dye constant and changing the concentration of OCl^-.

Since all of the reactions studied in this experiment involve a species (red dye) that will absorb visible light a Spectrophotometer (Spec 20) will be used to collect absorbance (A) data which can then be related to concentration (c) data using Beer's Law:

$$\mathbf{A = \varepsilon \ell c} \qquad (2)$$

where ℓ = pathlength of the cuvette (1.00 cm in this experiment) and ε = molar absorptivity for red dye.

MATERIALS: 100 mL volumetric flask (3), 50 mL beaker (2), 5 mL pipet (1), 2 mL pipet (3), 1 mL pipet (2), Spec-200 (1), cuvette (2), rubber stopper for cuvette (1), plastic droppers (2).

PROCEDURE:

SAFETY: ALWAYS wear safety goggles and an apron, and handle the intensely colored dye carefully to avoid stains on clothing. Sodium hypochlorite, household bleach, is a bronchial irritant. Keep solutions in the hood, and avoid breathing the vapors. Immediately wipe-up any spills of the red dye or bleach.

Part A. Prepare two red dye solutions from an initial stock solution, using serial-dilution method (See PRELAB) & determine absorbance

1. On data sheet, record the concentration of the stock solution to four decimal places

2. Obtain about 10 mL of red dye stock solution, in 50 mL beaker.

3. Rinse inside walls of pipet with a small amount of the red dye stock solution, then fill pipet and transfer 5.00 mL of the red dye into a volumetric flask. Carefully fill the flask up to the 100.0 mL mark with distilled water. Cap the flask and invert the solution several times to mix well.

4. Rinse the pipet again, this time with some of the dilute solution you just made. Pipet 5.00 mL of the dilute red dye solution (prepared in step 3), into another clean volumetric flask. Carefully fill the flask up to the 100.0 mL mark with distilled water. Cap the flask and invert the solution several times to mix well. Rinse the pipet with some of the more dilute solution you just made. <u>It is THIS SOLUTION that will be used in all reaction mixtures described in Part B.</u>

5. Using distilled water as a blank, follow the provided directions to prepare the Spec-200 for use.

6. Transfer 2.00 mL of your dilute solution from Part A (4.) into a clean, dry cuvette. Insert the cuvette with the dye into the sample compartment. Following the provided directions, scan the spectrum of the red dye. Set the wavelength of the Spec-200 to the wavelength with the highest absorbance.

7. Set the instrument to Absorbance mode and record the Absorbance, A, at your selected wavelength on the data sheet. *Note: From this you will be able to calculate the molar absorptivity, ε, of the red dye solution.*

Part B. Transmittance measurements of reaction mixtures

1. Obtain about 15 mL of hypocholorite solution, in 50 mL beaker. Record the weight percent on data sheet.

2. Following the provided directions, put the Spectronic 200 into Percent Transmittance, %T, mode.

3. Using pre-rinsed volumetric pipets, fill the cuvette with appropriate amounts of *dilute* dye solution and water for Reaction #1 as specified in the table below. *Note: Because this reaction will begin as soon as you mix the red dye and bleach solutions, <u>you must start timing as soon as the bleach is added.</u>*

4. Using a pipet, transfer the appropriate amount of bleach solution into a clean, dry test tube. Pour the bleach solution quickly and carefully from the test tube into the cuvette containing the dye solution to initiate the reaction. Stopper the cuvette, invert once to mix, then quickly wipe the cuvette with a lab tissue and insert into the Spec-200. Start recording time and percent transmittance readings. Record the percent transmittance every 30 seconds for 10 minutes or until the percent transmittance reaches 75%, whichever comes first. Record time vs percent transmittance on the data sheet.

5. For reaction #2, the same procedure can be used. After the initial absorbance measurement, take additional readings every 60 seconds for 20 minutes, or until the percent transmittance reaches 75%.

Reaction #	dye solution (mL)	deionized water (mL)	bleach solution (mL)
1	4.00	0.00	2.00
2	4.00	1.00	1.00

Clean up:

1. Be sure to remove the sample from the Spec-200! Discard all solutions in the sink. Wash and rinse glassware thoroughly to remove red dye and bleach residue. Shut down Spec-20 as instructed

Name ____________________________________ Section ____________

Name ____________________________________ Date _______________

DATA SECTION
Experiment 13H

Part A. Concentration and Absorbance of red dye solutions & mass percent of bleach

Note: Use proper significant figures and units.

1. Initial concentration of red dye stock solution: _____________________ mol/L

2. Record the Absorbance of the solution prepared in Part A (4.): __________(no units)

3. Mass percent of sodium hypochlorite in the bleach: ______________

Part B. Transmittance data for each reaction mixture

Time (sec)	% Transmittance Reaction #1

Time (sec)	% Transmittance Reaction #2

Name ________________________________ Section ___________

Name ________________________________ Date _____________

CALCULATIONS & DATA TREATMENT
Experiment 13H

Part A. Determining concentrations & molar absorptivity

Note: Use proper significant figures and units.

(A.1) Using $M_{(conc)}V_{(conc)} = M_{(dilute)}V_{(dilute)}$ and the initial concentration of the stock solution recorded in Part A, calculate the concentration of the red dye solutions you made in Part A (3.) and Part A (4.).

[red dye] Part A (3.) ______________

[red dye] Part A (4.) ______________

(A.2) Use Beer's Law and the absorbance recorded in Part A to calculate the molar absorptivity of the red dye solution.

Molar absorptivity _______________

(A.3) Mass percent of sodium hypochlorite in the bleach: ______________

(A.4) Assuming that the density of bleach solution is 1 g/mL, calculate the molarity of the sodium hypochlorite in the stock bleach solution provided.

(A.5) Using $M_{(conc)}V_{(conc)} = M_{(dilute)}V_{(dilute)}$, calculate the molarity of the sodium hypochlorite in reaction mixtures #1 and #2:

[bleach] Reaction #1 ______________

[bleach] Reaction #2 ______________

Part B: Data analysis

For a refresher on using Excel to perform calculations and graph data, check out the tutorials on the Chemistry Department website: https://www.usna.edu/ChemDept/_files/documents/excel-tutor/Excel%202013%20Tutorial.pdf

(B.1) Enter your time and percent transmittance data for Reaction #1 into an Excel spreadsheet.

(B.2) Create new columns for absorbance, [red dye], ln[red dye], and 1/[red dye]. Do not use your calculator - ENTER FUNCTIONS into the spreadsheet to perform each calculation!

Recall that: $$\frac{Abs}{\varepsilon \times \ell} = [\text{red dye}]$$

(B.3) Prepare three plots using your data from Reaction #1: [red dye] vs. time, ln[red dye] vs. time, and 1/[red dye] vs. time. The plot that visually appears the most "linear" tells you the order of the reaction, with respect to [red dye]. Perform linear regressions on each plot. The plot with the R^2 value closest to 1.0 is the most linear.

Note: Record which plot has an R^2 value closest to 1.0: ________________________

Record the order with respect to [red dye], **a***:* ________________________

(B.4) Enter time and absorbance data for Reaction #2 in the same Excel worksheet. Refer to your record of which plot was most linear (B.3) and construct this same plot for Reaction #2. Perform a linear regression on the plot, making sure to include the equation of the trend-line and R^2 value on each graph.

Note: Use the slope of each trend-line to solve for the order in bleach

Slope of trend-line Reaction #2: ________________

(B.5) By comparing the slopes of the trend-lines for Reactions #1 and #2 and the initial bleach concentrations calculated in (A.5), <u>determine **b**</u>, the order of the reaction with respect to bleach (i.e. OCl^-). Remember, the slopes of your graphs equal –k′ in each case, and k is constant for all cases.

$$\frac{k'_{EXP\#2}}{k'_{EXP\#1}} = \frac{k\,[OCl^-]^b_{EXP\#2}}{k\,[OCl^-]^b_{EXP\#1}}$$

(B.6) Write the experimental rate law based on the order of the red dye and the order of the OCl^- that you obtained in your analysis

(B.7) Calculate the rate constant for this reaction (remember to include proper units)

QUESTIONS
Experiment 13H

1. For Reaction #1, determine the initial (time = 0 minutes) and final (time = 15 minutes) concentrations of the hypochlorite ion. Does this justify the assumption that the rate law depends only on the red dye concentration for this reaction? Explain.

2. What does the rate law determined from this experiment tell us about the overall mechanism for this reaction? Specifically, based upon the observed rate law, what is the correct stoichiometry for the reactants in the rate-determining step? Explain.

Name ___________________________________ Section ____________

Date ______________

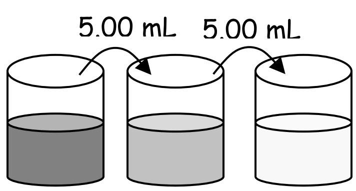
PRE-LAB EXERCISES
Experiment 13H

BRING YOUR LAPTOPS TO LAB

1. Calculate how many grams of sodium hypochlorite (NaOCl) solution were dissolved in 1.00 L of distilled water to give a 0.81 M stock solution.

2. Calculate the molarity of a solution of red dye #3 (MW 879.9 g/mol) if a 0.5028 g sample is diluted with distilled water to 100.00 mL in a volumetric flask.

3. An example of a "serial dilution" that you will perform in lab is: if you put a 5.00 mL aliquot of the solution from Question 2, into another 100.00 mL volumetric flask, and dilute it with distilled water to the 100.00 mL mark. That is the first dilution in a serial dilution. Then, if you put 5.00 mL of THIS new dilute solution into another 100.00 mL volumetric flask, and dilute with distilled water to the 100.00 mL mark, this is the second dilution in the series of "serial dilutions". The intensity of the color (and concentration of solute) will decrease with each dilution, as illustrated below.



Use the molarity you calculated in Question 2, and the data in the description, to calculate the molarities of the first dilution and second dilution.