An Inexpensive Kinetic Study: The Reaction of FD&C Red #3 (Erythrosin B) with Hypochlorite

Maher M. Henary and Arlene A. Russell*

Department of Chemistry and Biochemistry, University of California, Los Angeles, Los Angeles, CA 90049-1569; *russell@chem.ucla.edu

Kinetics constitutes a core topic in both the lecture and laboratory of general chemistry courses (1). While textbook examples and end-of-chapter exercises that students work with in the lecture are free of time constraints and temperature limitations, such is not the fortune of the laboratory. Reactions used in the laboratory must occur slowly enough to be detected by students, yet rapidly enough for them to obtain meaningful data in the few hours assigned to a laboratory period. Reactions should preferably occur near ambient temperatures, should be detected by simple analytical methods that are accessible to general chemistry students, should yield simple-order rate laws that verify or lead to textbook theory, and should employ reagents and products that are safe and do not generate hazardous waste.

Not surprisingly, a limited set of systems and procedures are generally used. The iodine clock reaction dominates the experiments in recently published manuals (2). But a few other clock reactions involving the oxidation of sulfite by iodate (3) and the reduction of permanganate by oxalate (4) provide options for this procedure. The hydrolysis of the α-butyraldehyde can be directly followed by titrating the hydrogen ion generated after the rate determining step (5). More frequently, direct monitoring occurs by observing the development or disappearance of a colored species in the reaction. These systems have the advantage of providing multiple time and concentration data points for a single rate run. Both the bromination of acetone and the hypochlorite oxidation of bromocresol green have been developed as inquiry-based experiments (6), which allow direct observation of the reaction progress. A few experiments use enzymes to deal with the time constraints of laboratory periods, but the reactions are often more complicated and beyond the calculus skills of general chemistry students (7, 8). Recently, this Journal (9) described the first-order hypochlorite oxidation of blue food coloring.

This article reports a new kinetics system involving the reaction of FD&C Red #3 and hypochlorite. The article also provides a modification to the oxidation of blue food coloring by using solid FD&C Blue #1, which lets students directly determine the molar absorptivity of the dye. Both systems are inexpensive (~5 cents/student) and allow students in a three-hour laboratory period to obtain the data to determine the order of the reaction with respect to the dye and the hypochlorite and also the rate constant as a function of temperature.

Since both FD&C Red #3 (erythrosin B, \( M = 879.9 \) g/mol) and FD&C Blue #1 (Brilliant Blue FCF, \( M = 789.9 \) g/mol) (10) are intensely colored, only small quantities of easily disposed waste are generated. Although sodium hypochlorite (household bleach) is a bronchial irritant, the small quantities used allow the reactions to be studied in test tubes on the bench top. Because of the extended conjugation within the dye molecule (Figure 1), the \( π-π^* \) absorptions occur in the visible region of the spectrum at 530 nm for the red food color. Students use desktop visible spectrophotometers to quantitatively follow the rate of disappearance of the colored reagent and thereby determine the rate laws.

Procedure

Because the reaction time for mixtures of bleach and diltue dye solution are short (5–15 min), pairs of students find it easier to record precise time and absorbance measurements than do students working independently. The large number of trials possible in a lab period provides more than enough data for both students to be involved in the data analysis. A full copy of the student procedure is available in the Supplemental Material.

Starting with the solid (~0.30 g), students prepare 100 mL of a standard solution of dye. Using volumetric flasks and pipets, the students then use a serial dilution procedure, which they develop or are given, to obtain a solution with a concentration approximately 1.7 \( \times 10^{-5} \) M. After measuring the absorbance of the solution (it should be in the 0.4–0.6 range), they calculate a value for the molar absorptivity of the dye. Fresh 6.0% or 6.15% household bleach, which is 0.81 M or 0.83 M sodium hypochlorite, serves as the oxidizing agent.

We recommend that students design a procedure varying first the concentration of the dye and then the bleach so that they have redundant data to determine the exponents in the rate law. A typical set of experimental conditions for Red #3 is given in Table 1.

![Figure 1. Structure of FD&C Red #3.](image)

| Table 1. Typical Experimental Conditions for Reaction of FD&C Red #3 with Bleach |
|-----------------|-----------------|-----------------|
| Trial | Dye Solution/mL | Water/mL | Bleach/mL |
| 1    | 2               | 3     | 1       |
| 2    | 2               | 2     | 2       |
| 3    | 4               | 1     | 1       |
| 4    | 2               | 1     | 3       |
| 5    | 3               | 2     | 1       |
| 6    | 5               | 0     | 1       |
The reactions are carried out in 13 × 100-mm disposable borosilicate-glass culture tubes, which serve as cuvettes in the spectrophotometers. The water and dye solutions are mixed in the tube. Timing begins when the prescribed quantity of bleach solution is added directly and forcefully into the tube using a 1-mL or 5-mL syringe. The tube is immediately put into the spectrophotometer and absorbance-time measurements are taken for 15 minutes or until the absorbance is less than 0.01.

Hazards and Disposal

Students should wear eye protection, lab coats, and gloves. They should handle the dye carefully to avoid spilling it on the balance or bench top. Skin contact is not known to create any health effects; solid particles in the eye (powder or dust) may cause pain and be accompanied by irritation. Sodium hypochlorite (household bleach) is corrosive and may cause severe bronchial irritation or damage to eyes and skin. Solutions should be kept covered or in a well ventilated area; breathing the vapors should be avoided. Spills of either reagent should be washed with large quantities of water.

Since these food coloring dyes are intensely colored, small quantities are used. Their nontoxic, aqueous solutions can be safely disposed of down the drain. The diluted solutions of sodium hypochlorite can also be safely disposed of in the drain with additional water.

Data Analysis

Using a computer spreadsheet program such as Excel, students set up a table for each trial, recording or calculating absorbance, [dye], ln[dye], and 1/[dye]. Plots of [dye] versus time, ln[dye] versus time, and [dye] versus time for each trial yield experimental evidence for first-order reactions for the dye. Figure 2 shows typical student graphs. Determination of the slope of the line yields the rate constant for the reaction. From a comparison of the slopes of the lines when the dye concentration is held constant and the initial bleach concentration varied, students can calculate the order of the reaction for the bleach and the rate constant for the reaction.

Results

• The molar absorptivity for FD&C Red #3 is 7.96 × 10^4 M^-1 cm^-1 at 530 nm.
• At room temperature the decomposition of Red #3 with hypochlorite is first order in both dye and bleach.
• The rate constant obtained through this procedure ranges from 3 × 10^{-2} to 5 × 10^{-2} M^{-1} sec^{-1}.

Summary

The rate law obtained

\[
\text{Rate} = k\left[\text{OCI}^-\right]\text{[Red #3]}
\]

is consistent with a nucleophilic attack of the hypochlorite on the dye. In studying the product mixture we have found one major component visible under UV light in the TLC of the colorless product mixture; however, we have been unable to characterize it. Were we to use this experiment in an organic chemistry laboratory course, we would take advantage of the fact that the reaction has not been characterized and that the products are unknown as a stepping stone to ask students to propose multiple mechanisms that fit the data and to evaluate the strengths and weaknesses of their proposed mechanisms based on molecular modeling studies similar to those recently described in this journal (10).
In the Laboratory

For a general chemistry class, the simplicity of the experiment, the unambiguous kinetics data that are obtained, and the rapidity with which the data can be acquired, allow students the opportunity to participate in the design of the trials they will study to lead to the rate law.

Reaction of Blue #1 with Bleach

The above procedure can be used for FD&C Blue #1. Approximately 0.15 g of solid is necessary to obtain solutions with absorbances in the 0.4–0.6 range. The molar absorption coefficient at 630 nm is determined by students to be approximately $2.6 \times 10^5 \text{M}^{-1} \text{cm}^{-1}$. The rate constants obtained are similar to those reported earlier (9).

Acknowledgments

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Supplemental Material

Instructions for the students and notes for the instructor are available in this issue of JCE Online.

Note

1. Both dyes, FD&C Red #3, and FD&C Blue #1, are available from Noveon Hilton Davis, Inc., Cincinnati, OH.

Literature Cited