

# A study of the rate of the reaction of chlorine bleach with blue dye

The purpose of this experiment is to determine the reaction order and the rate constant for the reaction of a food colourant (FD & C Blue #1), with household bleach, which is an aqueous solution of sodium hypochlorite.

The reaction is represented as



The rate law equation for eq 1 is

$$\text{rate} = k[\text{bleach}]^m[\text{blue dye}]^n. \quad \text{eq 2}$$

In this experiment we will determine the values for  $m$ ,  $n$  and  $k$ . That is, we will determine the reaction order of each reactant as well as the rate constant for the reaction at room temperature.

Since the bleach and the products are virtually colourless, and the total reaction time is around 10 minutes, the progress of the reaction can be followed in a class period using a Spec 20.

## Overview of the experiment

The disappearance of the colour of the blue dye as a function of time will be followed using the Spec 20.

The blue dye obeys the Beer-Lambert Law over the concentration range in this experiment.

## How do we determine the values of $m$ , $n$ and $k$ ?

Since the bleach and the products are virtually colourless, we can monitor the disappearance of the blue colour of the dye.

We will use NaOCl at a concentration much greater than the dye concentration. This means that eq 2 reduces to

$$\text{rate} = k_{\text{obs}}[\text{blue dye}]^n \quad \text{eq 3}$$

$$\text{where } k_{\text{obs}} = k[\text{bleach}]^m, \quad \text{eq 4}$$

and  $k_{\text{obs}}$  is the experimentally *observed* rate constant.

We simply monitor the progress of the reaction with the Spec 20. As time goes on, [blue dye] will decrease. That is, we record %T as a function of time. Enter the corresponding %T and time values into a spreadsheet program.

The absorbance can be determined using the equation

$$A = -\log(\%T/100). \quad \text{eq 5}$$

We can then convert absorbance values ( $A$ ) to [blue dye] with the Beer-Lambert Law and the given molar absorptivity value for the blue dye. ( $\epsilon = 1.38 \times 10^5 \text{ cm}^{-1} \text{ mol}^{-1} \text{ L}$ )

Recall the Beer-Lambert Law

$$A = l \cdot c \cdot \epsilon \quad \text{eq 6}$$

where  $l$ , the pathlength, is the distance that the light travels through the solution, i.e., the diameter of the cuvette. For the Spec 20,  $l=1.25 \text{ cm}$ , and is a constant.

## How to use the experimentally obtained data from the Spec 20 to determine the reaction order.

### First-order reaction

If the reaction is first-order in blue dye, the rate law equation is

$$\text{rate} = k_{\text{obs}}[\text{blue dye}]^1 \quad \text{eq 7}$$

where  $k_{\text{obs}}$  is the experimentally *observed* rate constant.

The integrated rate law equation for a first order reaction (determined by integrating) eq 7 is

$$\ln[\text{blue dye}] = -k_{\text{obs}}t + \ln[\text{blue dye}]_0. \quad \text{eq 8}$$

where  $t$  = time and  $[\text{blue dye}]_0 = [\text{blue dye}]$  at time = 0.

If we compare eq 8 to the equation of a straight line

$$y = mx + b \quad \text{eq 9}$$

we can see that a plot of  $\ln[\text{blue dye}]$  (on  $y$  axis) versus time will yield a straight line whose slope =  $-k_{\text{obs}}$ .

### Second-order reaction

If our reaction is second-order with respect to blue dye we have the rate law equation

$$\text{rate} = k_{\text{obs}}[\text{blue dye}]^2 \quad \text{eq 10}$$

The integrated form of eq 10 is

$$1/[\text{blue dye}] = k_{\text{obs}}t + 1/[\text{blue dye}]_0 \quad \text{eq 11}$$

If we compare this to the equation of a straight line (eq 9), we see that for a second-order reaction, a graph of  $1/[\text{blue dye}]$  versus time will be linear, with slope =  $k_{\text{obs}}$ .

Therefore, in order to determine the reaction order of blue dye, we simply plot two graphs:

1.  $\ln[\text{blue dye}]$  vs  $t$ , and
2.  $1/[\text{blue dye}]$  vs  $t$ .

Whichever graph is *linear* indicates the order of the reaction. The slope of the graph indicates the value of  $k_{\text{obs}}$  for that trial.

## Pre-lab

These pre-lab questions will help you with some of the calculations that you will need to do in this experiment. To get full value out of the questions, read this entire handout before beginning.

1. A 2.00-mL solution of  $\text{CoCl}_2$  ( $\epsilon = 4.53 \text{ cm}^{-1} \text{ mol}^{-1} \text{ L}$ ) is diluted to a total volume of 14.00 mL. It is then placed in a

Spec 20 and its transmittance read to be 28.2%. What is the  $[\text{CoCl}_2]$  in mol/L and % (m/v) of the original (before dilution) solution, given  $l = 1.25 \text{ cm}$ ?

2. a) Bleach is 5.25% (m/v) sodium hypochlorite, NaOCl. Convert this to concentration in mol/L.  
b) What is the  $[\text{NaOCl}]$  immediately after the solutions are mixed for each of trials 1 and 2? That is, you are finding  $[\text{NaOCl}]$  at  $t = 0$ .
3. Solve the equation

$$p = x(b)^y$$

for  $x$  and  $y$ , given

- i.  $p = 15.5$  when  $b = 3.7$   
ii.  $p = 2.74$  when  $b = 3.7/2$

## Procedure

Make sure that the Spec 20 has been warmed up for at least 15 minutes. Set it to 630 nm and zero the machine at 0%T and 100%T.

We need to carry out two trials. Measurements need to be as exact as possible.

In **trial #1**, 12.00 mL of blue dye solution (in a buret) will be quickly mixed with 1.0 mL of bleach (also in a buret). Without delay this solution will be poured into a cuvette, mixed well and inserted into a pre-calibrated Spec 20 (630 nm) in order to follow the rate.

In **trial #2**, 12.00 mL of blue dye solution will be added to 0.50 mL of NaCl solution (whose molar concentration must be the same as the concentration of NaOCl in bleach) and 0.50 mL of bleach. The equimolar solution of NaCl is used to maintain the same total ion concentration (i.e., ionic strength) between the two trials.

## Data analysis

When the two trials are complete, convert %T  $\rightarrow$  A  $\rightarrow$  [blue dye] for each trial. For each trial, plot the two graphs indicated above. The graph that is linear tells us the order of the reaction with respect to blue dye (i.e., whether "n" = 1 or 2), and the value of  $k_{\text{obs}}$  (from - slope).

You will have a unique value of  $k_{\text{obs}}$  for each trial and the value of "n".

Since we complete two different trials, each with the same [blue dye] but with a different, but known, [bleach], we will have two different eq 3s.

$$\text{rate} = k_{\text{obs}}[\text{blue dye}]^n \quad \text{eq 3}$$

$$\text{where } k_{\text{obs}} = k[\text{bleach}]^m \quad \text{eq 4}$$

Solving eq 4 for these two variables ( $k$ ,  $m$ ) in two simultaneous equations (hello mathematics!) will give us the rate constant,  $k$ ,

and the exponent "m". Round your value of "m" to the nearest integer. Substitute the rounded off value for "m" into each equation, i.e., for trial 1 and for trial 2. (How should the  $k$  values for trial 1 and for trial 2 compare?) Report the average value of  $k$ , with proper units and to the correct number of significant digits.

Finally, state the overall rate law equation for the reaction of bleach with blue dye, as

$$\text{rate} = \text{_____} [\text{blue dye}]^n [\text{bleach}]^m$$

## Notes and advice (and a question) for a successful experiment.

- The blue dye (FD & C #1) has an absorbance maximum at 630 nm.
- We will supply you with a solution of the food dye. (We use 18 drops of "Club House" Brand blue food colouring per litre of solution. The blue colouring comes in a set of four different food colours.)
- The blue dye follows the Beer-Lambert Law.
- For the blue dye,  $\epsilon = 1.38 \times 10^5 \text{ cm}^{-1} \text{ mol}^{-1} \text{ L}$ .
- Work as accurately, quickly and consistently as possible. After mixing the reactants in a beaker, get the solution into a cuvette and into the Spec 20 right away.
- Household bleach is 5.25% (m/v) NaOCl. Convert this to a mol/L concentration of sodium hypochlorite.
- We have for you an equimolar solution of NaCl.
- Any solution left over after filling the cuvette should be placed in a small beaker on top of a white piece of paper, next to the Spec 20. This will let you visually follow the reaction.
- You can't record too many data points.
- When %T = 90%, stop recording data points. You've reached the sensitivity limit of the Spec 20.
- Have data tables pre-formatted, or, even better, get your hands on a notebook computer and enter data as you collect it. Have your spreadsheet set up in advance.
- Why don't we simply use 12.00 mL blue dye and 0.50 mL bleach in trial 2?

## Submit a brief lab report including:

- Descriptive title for the experiment
- Abstract
- Three graphs per trial: [blue dye] vs time,  $\ln[\text{blue dye}]$  vs time,  $1/[\text{blue dye}]$  vs time .
- Provide a descriptive title for each graph, not simply "Y" vs "X". (put three graphs on a page)
- Calculations (data analysis, as previously in this handout) clearly laid out. Determine the rate constant for both trials and provide an average value for  $k$  with proper units.

## Conclusions

N.B. The abstract, calculations, conclusions are restricted to one page in length. Plot graphs separately, six to a page. Be sure to specify the units of the rate constant,  $k$ , and make reference to the temperature of the experiment. ■