**Kinetics of the reaction between bleach and food dye**

**Introduction**

Commercial bleach (usually about a 5 percent by mass solution of sodium hypochlorite) does not remove stains from clothing. Instead, the sodium hypochlorite reacts with the dye and oxidizes it to something that does not absorb visible light. (Unfortunately this oxidation is not selective, and overuse of bleach will also oxidize – and thus weaken – the material in your clothing. Cotton seems especially susceptible to this.)

The object of today’s experiment is to determine the rate law for the kinetics of the reaction between food dye and bleach. For our experimental setup and conditions, the rate of the reaction between food dye and bleach is found to depend only on the concentrations of those two species. Because of that, the rate law for the reaction kinetics may be written:

\[ \text{rate} = k \text{[dye]}^x \text{[bleach]}^y \]

We could use the method of initial rates to determine the values of \( x \) and \( y \) (as you’ve seen in class), but this is unnecessarily complex if the rate law is simple. Instead, we will use an alternative approach (that we have also seen in class), that being to use the integrated rate laws.

The integrated rate laws that we have studied in class are:

- **Zeroth:** \([A]_t = [A]_0 - kt\)
- **First:** \(\ln[A]_t = \ln[A]_0 - kt\)
- **Second:** \(1/[A]_t = 1/[A]_0 + kt\)

In each of the rate laws above, \([A]_0\) and \([A]_t\) are the concentration of species “A” at the start of the experiment, and after some time \((t)\) has elapsed. “\(k\)” is the reaction rate constant.

If a reaction follows zeroth-, first-, or second-order kinetics, then suitably modified data can be made to give a straight-line graph. For example, if a plot is made that has \(\ln[A]_t\) on the y axis, and time on the x axis, the slope of the resulting line (if straight) will be “-\(k\),” and the y-intercept will be \(\ln[A]_0\). Furthermore, if a straight line does result, we know that the reaction follows first-order kinetics. To determine if a reaction follows zeroth-, first-, or second-order kinetics, then, all that’s required is to plot the data in the various ways dictated by the equations above until a straight line is obtained.

There is one significant drawback which prevents us from applying this approach to the lab today, however, and that is that the integrated rate laws above only work when there is only one species in the differential rate law, and there are two in the reaction we are studying today.

We can get around this problem, however, using a method called “flooding.” When we “flood” a reaction, we use enough of one of the chemicals in it that the concentration of that reactant
is effectively constant throughout the reaction (because so little of it is reacted away). In the reaction today, we will be using excess quantities of bleach, so that our rate law becomes

\[ \text{rate} = k'[\text{dye}]^y \]

In the equation above, the new rate constant \( k' \) is the old rate constant \( k \) multiplied by the (constant) bleach concentration (raised to the power \( y \)); the \( y \)-axis variable therefore becomes the concentration of the dye.

We will be using absorbance to monitor the concentration of the dye throughout the reaction. Absorbance and concentration are directly proportional to each other, and because of this we may simply substitute absorbance in place of concentration in the three integrated rate law equations above when searching for our straight line.

We may also determine the dependence of the reaction kinetics on the concentration of the bleach. Because the straight line plots above give the rate constant as their slope, and because the slope is the product of the rate constant and \([\text{bleach}]^y\) (given our experimental conditions), when the starting concentration of bleach changes, the rate constant for our experiment should also change. So, for example, if a doubling of the bleach concentration produces a fourfold increase in the slope, we know that the order of the reaction kinetics with respect to the bleach must be 2.

**Equipment required**
To do the lab today, you will need:

- Two 50-mL beakers
- A Spectronic 20 and two cuvettes
- 2-mL, 4-mL, and 20-mL pipettes
- A pipette rack
- A 100-mL volumetric flask
Procedure

**Part A: Determination of $\lambda_{\text{max}}$**

1. You will be studying the reaction kinetics for either the blue or the green food dye, but not both. Choose the colour you prefer and perform the next steps for only that colour.
2. Obtain two drops of the undiluted food dye and place it in a 50 mL beaker. Add approximately 25 mL of water and mix.
3. Fill a cuvette approximately two thirds full with the solution you just prepared.
4. Fill another cuvette approximately two thirds full with distilled water. This will be your blank for spectrometer calibration.
5. Determine the absorbance of the solution you just prepared over the range from 350 to 650 nm in steps of 20 nm. (Remember to recalibrate the Spectronic 20 at each wavelength.)
6. Rescan the region of highest absorbance in steps of 5 nm, and note the wavelength that gives the highest absorbance. This is $\lambda_{\text{max}}$ and will be the wavelength you will use when studying the kinetics of the food colouring reaction.

**Part B: Solution preparation**

1. Obtain approximately 30 mL of undiluted bleach solution in a 50 mL beaker.
2. Pipette 20 mL of the undiluted bleach solution into a 100 mL volumetric flask. Dilute to the mark with distilled water and mix thoroughly.
Part C: Kinetics

Note: This reaction occurs very quickly; you will be taking readings once every ten seconds. Do not start the reaction until you are completely ready.

You will be determining the kinetics of the bleach-food colouring reaction using one of the following four sets of mixtures:

<table>
<thead>
<tr>
<th></th>
<th>Green food dye</th>
<th>Blue food dye</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Set 1</td>
<td>Set 2</td>
</tr>
<tr>
<td>Vol. H₂O</td>
<td>0</td>
<td>2.00 mL</td>
</tr>
<tr>
<td>Vol. Bleach</td>
<td>4.00 mL</td>
<td>2.00 mL</td>
</tr>
<tr>
<td>Vol. Dye</td>
<td>4.00 mL</td>
<td>4.00 mL</td>
</tr>
</tbody>
</table>

Two runs each should be made for the “A” and “B” parts of the set you choose.

1. Obtain a stopwatch from the back of the lab.
2. Choose the set for which you will be studying the kinetics, and obtain the appropriate diluted food dye solution. (It should be the same colour as the food dye for which you determined λ_max in part A.)
3. Pipette the diluted food dye solution and distilled water (if any) into a 50-mL beaker.
4. Pipette the diluted bleach solution (that you prepared in part B) into a disposable test tube.
5. Set the Spectronic 20 to the appropriate λ_max (determined in part A) and calibrate it. Use distilled water as your blank.
6. Get the stopwatch ready and, when it is, pour the bleach from the test tube into the beaker containing the food dye (from step 3) and start the stopwatch. Immediately transfer the mixture into a cuvette and place it into the Spectronic 20.
7. Record the absorbance (or percent transmittance) of the mixture once every ten seconds for 150 seconds.
**Calculations**

Prepare the following plots of each of your four runs:

- absorbance vs. t
- ln[absorbance] vs t
- 1/[absorbance] vs t

One of the three types of plots above should give a straight line. From that plot type, determine the average rate constant for your “A” and for your “B” mixtures. The graph that produces the straight line will tell you what the dependency of the reaction kinetics is on the food dye concentration.

Determine the order of the reaction kinetics with respect to the bleach by comparing the rate constants from the two graphs that gave you straight lines.

**Questions**

1. What additional data would you need to collect in order to determine the activation energy for this reaction?
2. A student consistently takes two seconds between noting the time and reading the transmittance from the Spectronic 20. Will this result in their calculated rate constant being higher than it should be, lower than it should be, or will it not affect their calculated rate constant? How do you know?