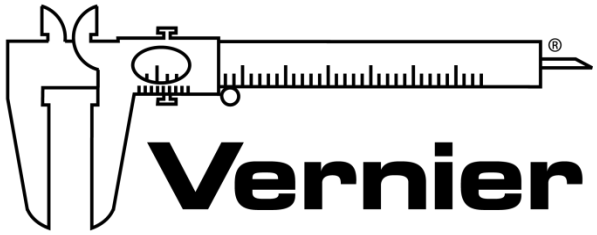
Challenging AP Chemistry Topics Made Easier



MEASURE. ANALYZE. LEARN.™

Vernier Software & Technology
www.vernier.com
888.837.6437

Nüsret (Nüs) Hisim
chemistry@vernier.com

NSTA National 2019

St. Louis, MO

HANDS-ON ACTIVITIES

The Determination of an Equilibrium Constant
- Go Direct SpectroVis Plus

Rate Law Determination of the Crystal Violet Reaction
- Go Direct SpectroVis Plus

Investigating the Kinetics of a Crystal Violet Reaction
- Go Direct SpectroVis Plus

The Determination of an Equilibrium Constant

The equilibrium state of a chemical reaction can be characterized by quantitatively defining its equilibrium constant, K_{eq}. In this experiment, you will determine the value of K_{eq} for the reaction between iron (III) ions and thiocyanate ions, SCN^-.

$$Fe^{3+}(aq) + SCN^-(aq) \leftrightarrow FeSCN^{2+}(aq)$$

When you mix amounts of Fe^{3+} and SCN^-, a reaction occurs to produce $FeSCN^{2+}$, but not all of the reactants react. Thus, your beaker (or flask or cauldron) will contain some of each of these three species, which is your equilibrium system. To learn more about the system, we need to figure out a way to count the number of different ions in the reaction mixture. That is the major objective of this experiment, and to achieve this objective you will take advantage of something about $FeSCN^{2+}$ — in aqueous solution it has a reddish color. The two reactants, Fe^{3+} and SCN^-, are essentially colorless in solution, thus the red color you will see when you conduct the reaction is produced by the $FeSCN^{2+}$ ions.

One of the more important numbers that help us understand an equilibrium system is called the equilibrium constant, K_{eq}. For the reaction between Fe^{3+} and SCN^-, the K_{eq} is defined by the equation

$$K_{eq} = \frac{[FeSCN^{2+}]}{[Fe^{3+}][SCN^-]}$$

To find the value of K_{eq} at a given temperature, it is necessary to determine the molar concentration of each of the three species in solution at equilibrium. You will determine the concentrations by using a Spectrometer to measure the amount of light of a specific wavelength that passes through a sample of the equilibrium mixtures. The amount of light absorbed by a colored solution is proportional to its concentration. The red $FeSCN^{2+}$ solution absorbs blue light, so you will determine an appropriate wavelength based on the absorbance spectrum of the solution. The wavelength will be close to, but not exactly, 470 nm.

In order to successfully evaluate this equilibrium system, it is necessary to conduct two separate tests. In Part I of the experiment, you will prepare a series of standard solutions of $FeSCN^{2+}$ from solutions of varying concentrations of SCN^- and constant concentrations of H^+ and Fe^{3+} that are in stoichiometric excess. The excess of H^+ ions will ensure that Fe^{3+} engages in no side reactions (to form $FeOH^{2+}$, for example) which could interfere with your measurements. In an excess of Fe^{3+} ions, the SCN^- ions will be the limiting reagent, thus all of the SCN^- will form $FeSCN^{2+}$ ions. The $FeSCN^{2+}$ complex forms slowly, taking at least one minute for the color to develop. It is best to take absorbance readings after a specific length of time has passed, between two and four minutes after preparing the equilibrium mixture. Do not wait much longer than 5 minutes to take readings, however, because the mixture is light sensitive and the $FeSCN^{2+}$ ions will slowly decompose.

In Part II of the experiment, you will prepare a new series of solutions that have varied concentrations of the SCN^- ions and constant concentrations of H^+ ions and Fe^{3+} ions. You will use the results of this test to accurately evaluate the equilibrium concentrations of each species and calculate the K_{eq} of the reaction.

OBJECTIVES

- Prepare and test standard solutions of $FeSCN^{2+}$ in equilibrium.
- Determine the molar concentrations of the ions present in an equilibrium system.
- Determine the value of the equilibrium constant, K_{eq}, for the reaction.

MATERIALS

Chromebook, computer, **or** mobile device
Vernier Spectral Analysis app
Go Direct SpectroVis Plus
plastic cuvette
four 10 mL graduated cylinders
one 50 mL graduated cylinder
seven small beakers (100–250 mL)
several plastic Beral pipets
0.200 M iron (III), Fe^{3+}, solution in 1.0 M HNO_3
0.0020 M iron (III), Fe^{3+}, solution in 1.0 M HNO_3
0.0020 M thiocyanate, SCN^-, solution
distilled water
lint free tissues or Kim® Wipes

PRE-LAB EXERCISE

For the solutions that you will prepare in Step 2 of Part I below, calculate the [$FeSCN^{2+}$]. Presume that all of the SCN^- ions react. In Part I of the experiment, mol of SCN^- = mol of $FeSCN^{2+}$. Record these values in the following table:

Beaker number	[$FeSCN^{2+}$]
1	
2	
3	
4	

PROCEDURE

Part I Prepare and Test Standard Solutions

1. Obtain and wear goggles.

2. Label four small beakers 1–4. Obtain small volumes of 0.200 M $Fe(NO_3)_3$, 0.0020 M SCN^-, and distilled water. Prepare four solutions according to the chart below. Use graduated cylinders to measure the solutions. Mix each solution thoroughly. Record the temperature of one of the solutions as the temperature for the equilibrium constant, K_{eq}. **DANGER**: *Iron (III) nitrate solution,* $Fe(NO_3)_3 \cdot 9H_2O$: *Causes skin and eye irritation. Do not breathe mist, vapors, or spray*. **WARNING**: *Potassium thiocyanate solution,* KSCN: *Causes eye irritation and mild skin irritation.*

   Important: The mixtures you will prepare are light sensitive. You need to measure the absorbance of these four mixtures within 2–5 minutes of preparing them.

Beaker	0.200 M $Fe(NO_3)_3$ (mL)	0.0020 M SCN^- (mL)	H_2O (mL)
1	5.0	4.0	41.0
2	5.0	3.0	42.0
3	5.0	2.0	43.0
4	5.0	1.0	44.0

3. Prepare a *blank* by filling a cuvette 3/4 full with 0.200 M $Fe(NO_3)_3$. To correctly use cuvettes, remember:
   - Wipe the outside of each cuvette with a lint-free tissue.
   - Handle cuvettes only by the top edge of the ribbed sides.
   - Dislodge any bubbles by gently tapping the cuvette on a hard surface.
   - Always position the cuvette so the light passes through the clear sides.

4. Launch Spectral Analysis. Connect the Go Direct SpectroVis Plus to your Chromebook, computer, or mobile device. Click or tap Absorbance vs. Concentration.

5. To calibrate the Spectrometer, place the blank cuvette in the Spectrometer and select Finish Calibration. **Note**: If necessary, wait for the Spectrometer to warm up before selecting Finish Calibration.

6. Determine the optimum wavelength for the equilibrium mixture.
   a. Empty the water from the blank cuvette. Using the solution in Beaker 1, rinse the cuvette twice with ~1 mL amounts and then fill it 3/4 full. Wipe the outside with a tissue and place the cuvette in the Spectrometer.
   b. The live graph will update with the spectrum of the sample. Click or tap the desired wavelength or enter the Wavelength. Click or tap Done. **Note**: The λ max should be 400–480 nm.

7. Collect absorbance-concentration data for the four standard equilibrium mixtures.
   a. Leave the cuvette, containing the Beaker 1 mixture, in the device.
   b. Click or tap Collect to start data collection. After the absorbance reading stabilizes, click or tap Keep and enter the value for the concentration of $FeSCN^{2+}$ from your Pre-Lab calculations. Click or tap Keep Point. The absorbance and concentration values have now been saved for the first solution.
   c. Discard the cuvette contents as directed. Using the solution in Beaker 2, rinse the cuvette twice with ~1 mL amounts, and then fill it 3/4 full. Place the cuvette in the device, wait for the value displayed on the screen to stabilize, and click or tap Keep. Enter the value for the concentration of $FeSCN^{2+}$ in Beaker 2, then click or tap Keep Point.
   d. Repeat Part c of this step to measure the absorbance of the solutions in Beakers 3 and 4. **Note**: Wait until Step 10 to test the unknown.
   e. When you have finished testing the standard solutions, click or tap Stop to stop data collection.
8. Display a graph of absorbance *vs.* concentration with a linear regression curve.
   a. Click or tap Graph Tools, , and choose Edit Graph Options.
   b. Enter **0** for both the x-axis Left value and the y-axis the Bottom value.
   c. Dismiss the Graph Options box. Your graph will now include the origin (0,0).
   d. Click or tap Graph Tools, , and choose Apply Curve Fit.
   e. Select Linear as the curve fit. Click or tap Apply. The graph should indicate a direct relationship between absorbance and concentration, a relationship known as Beer's law. Record the linear fit equation in your data table. **Important**: Do not remove the curve fit. You will use the best-fit line equation in Part II.

Part II Prepare and Test Equilibrium Systems

9. Label three new small beakers A–C. Prepare the solutions according to the chart below. Use 10.0 mL graduated cylinders to measure the solutions. Mix each solution thoroughly. **Note**: You are using 0.0020 M $Fe(NO_3)_3$ in this test. **WARNING**: *Iron (III) nitrate solution,* $Fe(NO_3)_3 \cdot 9H_2O$: *Causes skin and eye irritation. Do not breathe mist, vapors, or spray.*

Beaker	0.0020 M $Fe(NO_3)_3$ (mL)	0.0020 M SCN^- (mL)	H_2O (mL)
A	3.00	3.00	4.00
B	3.00	4.00	3.00
C	3.00	5.00	2.00

10. Collect absorbance-concentration data for the three beakers of equilibrium mixtures.

    a. Using the solution in Beaker A, rinse the cuvette twice with ~1 mL amounts and then fill it 3/4 full. Wipe the outside with a tissue and place the cuvette in the device. Write down, in your data table, the absorbance of the sample in Beaker A. Click or tap Graph Tools, , and enable Interpolate to determine the concentration of the sample. Dismiss the Graph Tools box and click or tap the graph to interpolate.

    b. Click or tap the linear regression line to find the $FeSCN^{2+}$ concentration for the sample in Beaker A. Write down the concentration in your data table.

    c. Discard the cuvette contents as directed. Rinse and fill the cuvette with the solution in Beaker B and place it in the device. After the reading stabilizes, write down the absorbance in your data table. Click or tap the linear regression line to find the $FeSCN^{2+}$ concentration for the sample in Beaker A. Write down the concentration in your data table.

    d. Repeat Step c for the mixtures in Beaker C.

DATA TABLE

Part I

Temperature: _____°C

Beaker	[$FeSCN^{2+}$]	Absorbance
1		
2		
3		
4		

Linear regression equation	

Part II

Beaker	Absorbance	[$FeSCN^{2+}$] at equilibrium
A		
B		
C		

Calculating Equilibrium Concentrations

A common method that is used to organize and calculate the concentrations of the species in an equilibrium system is colloquially known as an I.C.E. chart. "I.C.E" stands for *I*nitial concentration, *C*hange in concentration, and the *E*quilibrium concentration. The initial concentrations of the Fe^{3+} and the SCN^- ions can be calculated from the mixing chart in Part II, Step 10. You have already determined the equilibrium concentration of the $FeSCN^{2+}$ ions by completing the analysis in Part II. The rest is a little bit of math.

BEAKER A

	Fe^{3+}	SCN^-	$FeSCN^{2+}$
Initial			0.00
Change			
Equilibrium			

BEAKER B

	Fe^{3+}	SCN^-	$FeSCN^{2+}$
Initial			0.00
Change			
Equilibrium			

BEAKER C

	Fe^{3+}	SCN^-	$FeSCN^{2+}$
Initial			0.00
Change			
Equilibrium			

DATA ANALYSIS

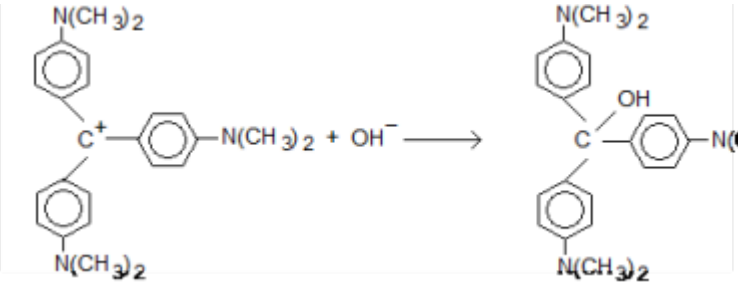
1. (Part II) Use your data to determine the $[Fe^{3+}]$, $[SCN^-]$, and $[FeSCN^{2+}]$ at equilibrium for each of the mixtures that you prepared in Part II. Complete the table below and give an example of your calculations.

	A	B	C
$[FeSCN^{2+}]$			
$[Fe^{3+}]$			
$[SCN^-]$			

2. Calculate the value of K_{eq} for the reaction. Explain how you used the data to calculate K_{eq}.

Rate Law Determination of the Crystal Violet Reaction

In this experiment, you will observe the reaction between crystal violet and sodium hydroxide. One objective is to study the relationship between concentration of crystal violet and the time elapsed during the reaction. The equation for the reaction is shown here.



A simplified (and less intimidating!) version of the equation is:

CV^+ (aq)	+	OH^- (aq)	→	CVOH
(crystal violet)		(hydroxide)		(aq)

The rate law for this reaction is in the form: rate = $k[CV^+]^m[OH^-]^n$, where k is the rate constant for the reaction, m is the order with respect to crystal violet (CV^+), and n is the order with respect to the hydroxide ion. Because the hydroxide ion concentration is more than 1000 times as large as the concentration of crystal violet, $[OH^-]$ will not change appreciably during this experiment. Thus, you will find the order with respect to crystal violet (m), but not the order with respect to hydroxide (n).

As the reaction proceeds, a violet-colored reactant will be slowly changing to a colorless product. You will measure the color change with a Spectrometer. The crystal violet solution used in this experiment has a violet color, of course, thus the Colorimeter users will be instructed to use the 565 nm (green) LED. Spectrometer users will determine an appropriate wavelength based on the absorbance spectrum of the solution. We will assume that absorbance is proportional to the concentration of crystal violet (Beer's law). Absorbance will be used in place of concentration in plotting the following three graphs:

- Absorbance *vs*. time: A linear plot indicates a *zero order* reaction (k = –slope).
- ln Absorbance *vs*. time: A linear plot indicates a *first order* reaction (k = –slope).
- 1/Absorbance *vs*. time: A linear plot indicates a *second order* reaction (k = slope).

Once the order with respect to crystal violet has been determined, you will also be finding the rate constant, k, and the half-life for this reaction.

OBJECTIVES

- Observe the reaction between crystal violet and sodium hydroxide.
- Monitor the absorbance of the crystal violet solution with time.
- Graph absorbance *vs*. time, ln absorbance *vs*. time, and 1/absorbance *vs*. time.
- Determine the order of the reaction.
- Determine the rate constant, *k*, and the half-life for this reaction.

MATERIALS

Chromebook, computer, **or** mobile device
Vernier Spectral Analysis app
Go Direct SpectroVis Plus
Temperature Probe or thermometer
5 plastic cuvettes
1 L beaker
two 10 mL graduated cylinders
0.10 M sodium hydroxide, NaOH, solution
2.5×10^{-5} M crystal violet solution
ice
two 100 mL beakers
50 mL beaker
watch with a second hand

PROCEDURE

1. Obtain and wear goggles.

2. Use a 10 mL graduated cylinder to obtain 10.0 mL of 0.10 M NaOH solution. **WARNING**: *Sodium hydroxide solution,* NaOH: *Causes skin and eye irritation.* Use another 10 mL graduated cylinder to obtain 10.0 mL of 2.5×10^{-5} M crystal violet solution. **WARNING**: *Aqueous crystal violet: May be harmful if swallowed. May cause skin irritation and eye damage.*

3. Prepare a blank by filling a cuvette 3/4 full with distilled water. To correctly use cuvettes, remember:

   - Wipe the outside of each cuvette with a lint-free tissue.
   - Handle cuvettes only by the top edge of the ribbed sides.
   - Dislodge any bubbles by gently tapping the cuvette on a hard surface.
   - Always position the cuvette so the light passes through the clear sides.

4. Launch Spectral Analysis. Connect the Go Direct SpectroVis Plus to your Chromebook, computer, or mobile device. Click or tap Absorbance vs. Time.

5. To calibrate the Spectrometer, place the blank cuvette in the Spectrometer and select Finish Calibration. **Note**: If necessary, wait for the Spectrometer to warm up before selecting Finish Calibration.

6. Determine the optimum wavelength for examining the crystal violet solution.

   a. Empty the blank cuvette and rinse it twice with small amounts of 2.5×10^{-5} M crystal violet solution. Fill the cuvette about 3/4 full with the crystal violet solution and place it in the Spectrometer.

   b. The live graph will update with the spectrum of the sample. Click or tap the desired wavelength or enter the Wavelength. Click or tap Done.

   c. Remove the cuvette from the Spectrometer and dispose of the crystal violet solution as directed.

7. *Do this quickly!* To initiate the reaction, simultaneously pour the 10 mL portions of crystal violet and sodium hydroxide into a 250 mL beaker and stir the reaction mixture with a stirring rod. Empty the water from the cuvette. Rinse the cuvette twice with ~1 mL amounts of the reaction mixture, fill it 3/4 full, and place it in the device. Click or tap Collect to start data collection.

8. Stop data collection when the reaction is complete (about 200 seconds). Discard the beaker and cuvette contents as directed by your instructor.

9. Analyze the data to decide if the reaction is zero, first, or second order with respect to crystal violet.
   - Zero Order: If the current graph of absorbance *vs*. time is linear, the reaction is *zero order*.
   - First Order: To see if the reaction is first order, it is necessary to plot a graph of the natural logarithm (ln) of absorbance *vs*. time. If this plot is linear, the reaction is *first order*.
   - Second Order: To see if the reaction is second order, plot a graph of the reciprocal of absorbance *vs*. time. If this plot is linear, the reaction is *second order*.

10. Create a calculated column, ln Absorbance, and add a linear curve fit to the graph ln Absorbance *vs*. time:

    a. In the Absorbance column header in the table, click or tap More Options, ⋯, and choose Add Calculated Column.

    b. Enter **ln Absorbance** as the Name and leave the Units field blank.

    c. Click or tap Insert Expression and choose Aln(X) as the expression.

    d. Confirm that Parameter A is set to **1** and that Absorbance is set to **Column X**.

    e. Click or tap Apply. A graph of ln absorbance *vs*. time is displayed.

    f. To see if the relationship is linear, click or tap Graph Tools, , and choose Apply Curve Fit.

    g. Select Linear as the curve fit.

    h. Record the slope as the rate constant, *k*, and dismiss the Linear curve fit box.

11. Create a calculated column, 1/Absorbance, and then plot a graph of 1/Absorbance *vs*. time:
    a. In the data table, click or tap More Options, ⋯, in the Absorbance column header, and then choose Add Calculated Column.
    b. Enter **1/Absorbance** as the Name and leave the Units field blank.
    c. Click or tap Insert Expression and choose A/X as the expression.
    d. Confirm that Parameter A is set to **1** and that Absorbance is set to **Column X**.
    e. Click or tap Apply.
    f. To display a graph of 1/Absorbance *vs*. time, click or tap the y-axis label and select only 1/Absorbance.
    g. To see if the relationship is linear, click or tap Graph Tools, , and choose Apply Curve Fit.
    h. Select Linear as the curve fit and click or tap Apply.
    i. Record the slope as the rate constant, *k*, and dismiss the Linear curve fit box.
12. (Optional) To see any of the three graphs again, click or tap the y-axis label and choose the column you want to display. Export, download, or print the most linear graph.

PROCESSING THE DATA

1. Was the reaction zero, first, or second order, with respect to the concentration of crystal violet? Explain.
2. Calculate the rate constant, *k*, using the *slope* of the linear regression line for your linear curve (*k* = –slope for zero and first order and *k* = slope for second order). Be sure to include correct units for the rate constant. **Note**: This constant is sometimes referred to as the *pseudo rate constant*, because it does not take into account the effect of the other reactant, OH^-.
3. Write the correct rate law expression for the reaction, in terms of crystal violet (omit OH^-).
4. Using the printed data table, estimate the half-life of the reaction; select two points, one with an absorbance value that is about half of the other absorbance value. The *time* it takes the absorbance (or concentration) to be halved is known the *half-life* for the reaction. (As an alternative, you may choose to calculate the half-life from the rate constant, *k*, using the appropriate concentration-time formula.)

Investigating the Kinetics of a Crystal Violet Reaction

Spectroscopy can be used to determine the concentration of a substance in an aqueous solution. Spectroscopy can also be used to measure the progress of a chemical reaction. In this investigation, the objective is to use spectroscopy to learn more about a chemical reaction. Further, the results of your investigation should provide sufficient evidence to describe the kinetics of a reaction and write the *rate law*.

The rate law of a chemical reaction describes, in equation form, the effect each reactant has on the progress of the reaction. For a generic reaction equation, A + B → C + D, the rate law is written as rate = $k[A]^x[B]^y$, where the exponents *x* and *y* refer to the order of the reaction with respect to the given reactant. The order of a reactant is established by determining the effect of concentration of a reactant on the rate at which the reaction proceeds. Commonly, order is determined to be zero, first, or second, and expressed in the rate law as an exponent of 0, 1, or 2.

When a solution of the organic indicator crystal violet reacts with a solution of sodium hydroxide, one of the results of the reaction is a color change. The purple color of the crystal violet solution disappears as the reaction proceeds to conclusion. How and why a chemical reaction proceeds in a certain manner is part of the study of chemical reactions called *kinetics*.

In the Initial Investigation, you will use a Vernier SpectroVis Plus Spectrophotometer to measure the absorbance of a series of standard solutions of crystal violet. With that information, you will devise a plan for conducting the reaction between solutions of crystal violet and sodium hydroxide, from which the rate law, with respect to crystal violet, can be written.

PRE-LAB ACTIVITY

Consider the graph of the absorbance spectrum of a 2.5×10^{-5} M crystal violet solution shown in Figure 1.

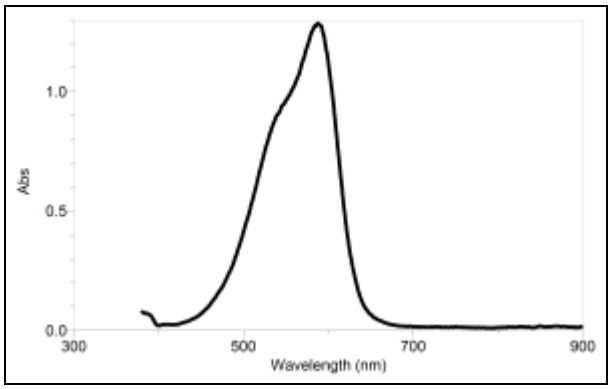


Figure 1

1. What is the best (optimal) wavelength, or wavelength range, at which to measure the absorbance of a set of five crystal violet solutions, if the maximum concentration is 2.5×10^{-5} M?

2. In the Initial Investigation, you will prepare five solutions of crystal violet and measure the absorbance of the solutions at the wavelength you selected in Question 1. You will need 10 mL of each solution. Complete the Table 1 to help you plan for the Initial Investigation.

Table 1

Concentration (mol/L)	Volume 2.5×10^{-5} M crystal violet (mL)	Volume distilled water (mL)
2.5×10^{-5}	10.0	0.0

3. Conduct research to find and write the balanced equation for the reaction between aqueous solutions of crystal violet and sodium hydroxide.

4. Conduct research to find and write the rate law for the reaction between aqueous solutions of crystal violet and sodium hydroxide. Explain all the components of the rate law.

INITIAL INVESTIGATION

In the Initial Investigation, you will measure the absorbance of a set of crystal violet solutions at a given wavelength.

1. Obtain and wear goggles.

2. To prepare the samples, obtain small volumes of 2.5×10^{-5} M crystal violet solution and distilled water. Prepare a set of serial dilutions of the stock crystal violet solution according to Table 1 that you prepared in Pre-Lab Question 2. **WARNING**: *Aqueous crystal violet: May be harmful if swallowed. May cause skin irritation and eye damage.*

3. Prepare a *blank* by filling a cuvette 3/4 full with distilled water. To correctly use cuvettes, remember

   - Wipe the outside of each cuvette with a lint-free tissue.
   - Handle cuvettes only by the top edge of the ribbed sides.
   - Dislodge any bubbles by gently tapping the cuvette on a hard surface.
   - Always position the cuvette so the light passes through the clear sides.

4. Set up the spectrophotometer and data-collection software.
   a. Launch Spectral Analysis.
   b. Connect the Go Direct SpectroVis Plus Spectrophotometer to your Chromebook, computer, or mobile device.
   c. Click or tap Absorbance vs. Concentration.
5. Calibrate the spectrophotometer.
   a. Place the blank cuvette in the spectrophotometer.
   b. Select Finish Calibration. **Note**: If necessary, wait for the spectrophotometer to warm up before selecting Finish Calibration.
6. Determine the optimal wavelength for crystal violet.
   a. Remove the blank cuvette from the spectrophotometer. Refill the cuvette with the stock solution of crystal violet (solution of greatest molar concentration).
   b. The live graph will update with the spectrum of the sample. Click or tap the desired wavelength or enter the Wavelength. Click or tap Done.
7. Collect absorbance-concentration data for the crystal violet standard solutions.
   a. With the cuvette of crystal violet solution still in the spectrophotometer, start data collection.
   b. After the value displayed on the screen has stabilized, select Keep and enter the concentration in mol/L. Select Keep Point. The absorbance and concentration values have now been stored for the first crystal violet solution.
   c. Remove the cuvette, pour out the solution, and rinse the cuvette. Refill the cuvette with a new crystal violet standard solution. Place the cuvette in the spectrophotometer.
   d. After the value displayed on the screen has stabilized, select Keep and enter the concentration in mol/L. Select Keep Point.
   e. Repeat the necessary steps to store concentration values for the remaining standard solutions.
   f. After the final standard solution has been measured, stop data collection.

PLANNING FOR THE FINAL INVESTIGATION

Based on the results of the Initial Investigation, develop a method for measuring the change in the concentration of a crystal violet solution as it reacts with sodium hydroxide. The objective is to collect data that is sufficiently valid and reliable to help describe and quantify the kinetics of the reaction. Keep in mind that the color of the solution will slowly fade as the reaction proceeds. Consider the following issues as you develop your plan:

- What is the linear fit (best fit line) equation for the set of crystal violet standards measured in the Initial Investigation? What does the slope of this line tell you about the standard solutions?
- What is the relationship between the molar concentration of a crystal violet solution and its absorbance of a specific wavelength of visible light?

- How does the testing of a series of standard solutions help describe what will happen during a reaction where the color of a solution is disappearing?
- How quickly, or slowly, should a reaction proceed in order to achieve the best readings of its change in color?
- In the Initial Investigation, the molar concentration of the NaOH solution was orders of magnitude more concentrated than the crystal violet solution. How does this affect the tests you need to run to determine the order of the reaction with respect to NaOH?

Your plan should provide sufficient data to write the rate law for the reaction between aqueous solutions of crystal violet and sodium hydroxide. **WARNING**: *Sodium hydroxide solution,* NaOH: *Causes skin and eye irritation*.

FINAL INVESTIGATION

As you carry out your approved plan, consider the following points

- You should collect data in absorbance *vs*. time mode. To change modes, click or tap File, , and choose New Experiment. Click or tap Absorbance vs. Time.
- The default parameters for time-based data collection are a duration of 200 seconds and a rate of 2 seconds per sample. It is wise to lengthen the duration to ensure that all the necessary absorbance readings are collected.
- Confirm that you are using the correct wavelength for your Final Investigation. If you need to change the wavelength, click or tap the Absorbance meter. The live graph will update with the spectrum of the sample. Click or tap the desired wavelength or enter a value for the Wavelength. Click or tap Done.

ANALYZING RESULTS

When preparing your report, include

- A statement of the results: What is the rate law for the reaction between solutions of crystal violet and sodium hydroxide?
- A description of the testing method used to determine the order of the reaction with respect to crystal violet
- A description of the method used to determine the order of the reaction with respect to sodium hydroxide
- An analysis of the data and calculations leading to the determination of the value of the rate law constant, *k*

Additional items to consider including in your report

- A comparison of your results with those of other groups
- Recommended modifications to the procedure that would increase accuracy, save time, or ensure that liquids are handled more efficiently and safely