10B. MEASURING THE SPEED OF A REACTION

(Spectrometer Version)

Initial Question

You have seen instructions on bottles of medicine instructing you, for example, to take "two capsules every four hours." How do scientists come up with how often to take a medication? The answer is that they have done experiments that quantify how quickly the medicine is metabolized by the body. In other words, they develop equations that predict how long it will be before the concentration drops too low to have an effect on your symptoms. Such problems require scientists to make quantitative predictions, that is, to find an equation for the reaction.

How do you determine the speed of a reaction?

Learning Objectives

Students determine the order of a reaction and the effect of variables on the reaction rate.

LO 4.2 / The student is able to analyze concentration versus time data to determine the rate law for a zeroth-, first-, or second-order reaction.

SP 4.2 / The student can *design a plan* for collecting data to answer a particular scientific question.

SP 5.3 / The student can *evaluate the evidence provided by data sets* in relation to a particular scientific question.

Time Requirement

Preparation time: 20 minutes / Lab activity: 90 minutes

Materials and Equipment

Model 1
- Spectrometry Application
- Spectrometer and Cuvettes
- Test tubes (2), 20- to 25-mL
- Volumetric pipets (2), 10-mL

- Beaker, 50-mL
- 5.0×10^{-5} M Crystal violet ($C_{25}H_{30}N_3Cl$), 10 mL
- 0.2 M Sodium hydroxide (NaOH), 10 mL
- Distilled water for calibration, about 10 mL
- Kimwipes®

Model 2
- Spectrometry Application
- Spectrometer and Cuvettes
- Temperature sensor
- Beakers (2), 50-mL
- Beakers (2), 400-mL^2
- Volumetric pipets (2), 10-mL^2

- 0.2 M Sodium hydroxide (NaOH), 40 mL
- 5.0×10^{-5} M Crystal violet ($C_{25}H_{30}N_3Cl$), 40 mL
- Hot plate
- Ice
- Distilled water for calibration, about 10 mL
- Kimwipes®

Safety

Add these important safety precautions to your normal laboratory procedures:

- Sodium hydroxide is caustic and should be handled with special care. In case of contact with your skin, wash off the sodium hydroxide with a large amount of water.

- Crystal violet will stain skin and clothing, so be cautious in handling.

Getting Your Brain in Gear

1. Fill in the *y*-axis label that will result in a linear relationship for each order of reaction.

| Zero order reactions | First order reactions | Second order reactions |
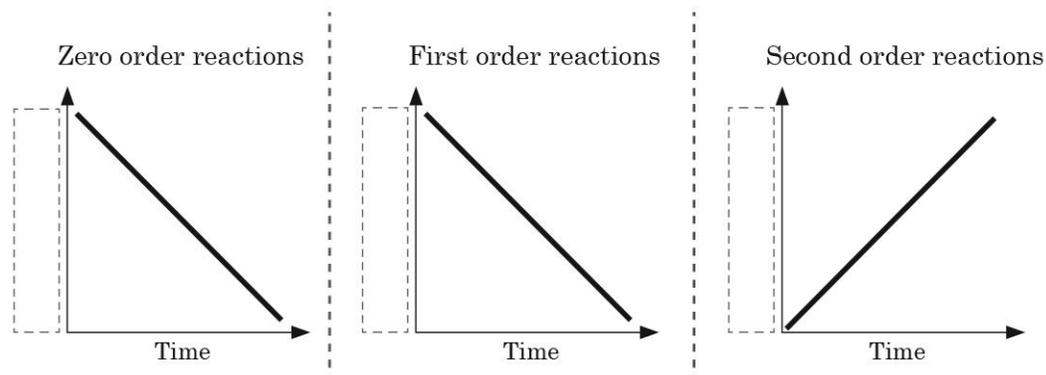
2. The compound crystal violet has a purple color in an aqueous solution. When it reacts with sodium hydroxide, crystal violet fades to colorless.

$$C_{25}H_{30}N_3Cl(aq) \quad + OH^-(aq) \rightarrow \quad (C_{25}H_{30}N_3Cl)OH^-(aq)$$

(Purple) \qquad\qquad\qquad\qquad (Colorless)
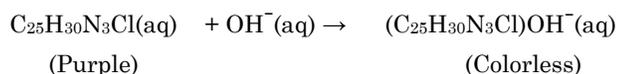
a. What sensor could we use to measure the concentration of the crystal violet over time?

_____

b. The reaction requires much more sodium hydroxide than crystal violet to react in a reasonable amount of time. The sodium hydroxide solution to be used is about 50,000 times more concentrated than the crystal violet solution. Even if all of the crystal violet is consumed, will the sodium hydroxide concentration change much?

_____

_____

c. If the sodium hydroxide concentration does not change much, what will the reaction order with respect to sodium hydroxide be?

_____

_____

3. The crystal violet compound is a dark blue-purple color in solution. Its absorbance at 583nm is shown below as a function of concentration.

Optical absorbance of crystal violet at 583 nm
Pathlength = 1.00 cm

$y = (9270)x + (-0.0627)$
$r = 0.988$
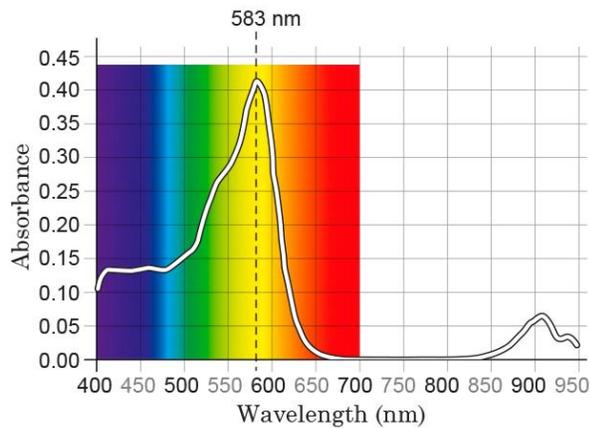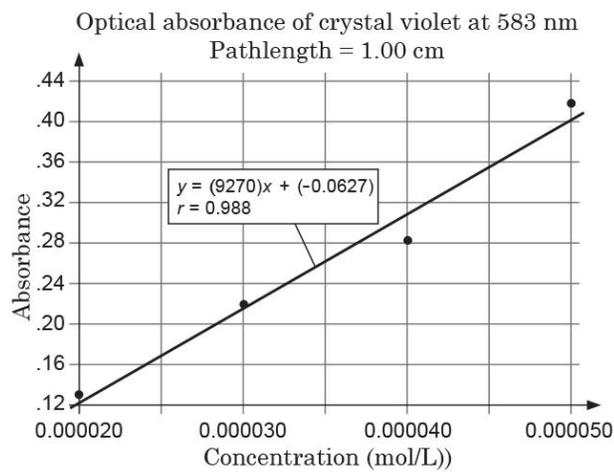
583 nm

a. Why was 583 nm chosen to measure the absorbance?

_____

_____

b. Just using the graph, if you measure the absorbance of a solution to be 0.2, what is the concentration of crystal violet?

_____

c. Use the line of best fit to write an equation relating concentration and absorbance.

   NOTE: The equation of the line of best fit is shown in the graph.

d. Solve this equation for the concentration.

e. If the absorbance was found to be 0.95, what is the concentration of crystal violet?

MODEL 1

Building Model 1 – Collecting Kinetics Data

1. Connect the spectrometer to the data collection system using a USB cable connection, or wirelessly connect to the system through Bluetooth pairing.

2. Open the Spectrometry application.

3. Select Analyze Solution from the menu at the top of the screen.

4. Select Calibrate Dark from the Menu at the bottom of the screen. The Spectrometer will turn off all of its lights and perform the calibration. A check mark will appear when the calibration is finished.

5. Add distilled water to a cuvette. This should be the same distilled water that was used as a solvent for the solutions being analyzed. Place the cuvette into the spectrometer. Follow the cuvette handling guidelines listed below for the remainder of the investigation.
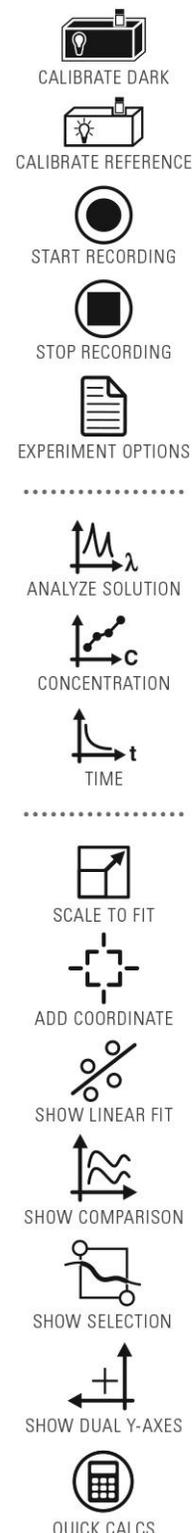
   Always handle the cuvette by the ridged sides.

   Wipe off any fingerprints using a lint free wipe (such as Kimwipes).

   Place the cuvette into the spectrometer so that the ridged sides are facing the violet and green light icons and the clear sides face the white light and absorbance spectrum icons. The white light is what will pass through the samples.

6. Select Calibrate Reference from the menu at the bottom of the screen. A check mark will appear when the calibration is complete.

7. Fill a cuvette with 5.0×10^{-5} M crystal violet solution. Place the cuvette into the spectrometer as you did in the calibration.

8. Select the red Record circle at the bottom left of the screen to start analyzing the solution. (It changes into a square while data is being collected.) After the reading stabilizes, select the red Stop Recording square to stop data collection.

9. Select Scale To Fit to rescale your data.

10. Use the Add Coordinate tool to locate a wavelength to analyze on the curve.

    a. Move it to the box that has appeared on the graph and drag the box slowly toward the curve. As you get near the curve an arrow will appear that indicates a specific wavelength on the curve. Releasing the box will snap the box to the point on the curve the arrow is pointing to.

    b. Drag the box along the curve to find a desirable wavelength to analyze. This is usually a high point on the curve. If your curve plateaus near the top of the graph, the absorbance is too large in that area to be used for analysis and another wavelength should be used. Select the check mark when you have found the greatest absorbance. (If the check mark is not visible, tap the coordinates box to make it appear.)
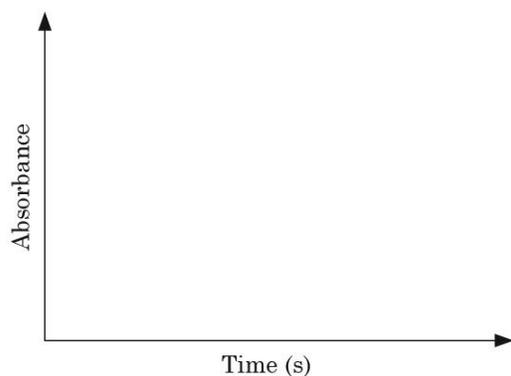
11. Select Analyze over Time from the menu at the top of the screen.

CALIBRATE DARK

CALIBRATE REFERENCE

START RECORDING

STOP RECORDING

EXPERIMENT OPTIONS

ANALYZE SOLUTION

CONCENTRATION

TIME

SCALE TO FIT

ADD COORDINATE

SHOW LINEAR FIT

SHOW COMPARISON

SHOW SELECTION

SHOW DUAL Y-AXES

QUICK CALCS

12. In the white box labeled slope (m) type in the value 9270 and in the white box marked y-intercept (b) type in -0.0627. These are the slope and intercept used in Getting your Brain in Gear and are specific to this reaction.

13. Use a volumetric pipette place 2.0 mL of 5.0×10^{-5} M crystal violet into a test tube.

14. Use a different volumetric pipette to place 2.0 ml of 0.2 M sodium hydroxide (NaOH) into a different test tube.

15. Pour the contents of both graduated cylinders into a third test tube. Then put that solution into a cuvette and quickly put it into the spectrometer and start data collection.

16. Use Scale To Fit to rescale your data. Allow the spectrometer to collect data for 3 minutes or until the absorbance is at least half the initial absorbance value Then stop data collection.

17. Sketch the absorbance versus time data on the Model 1 Graph. Select Show Linear Fit to create a best fit line and display the equation for the line. Included in the linear fit display is the r value for the line.

18. Click on the Y axis label to change it to Concentration. Use Quickcalcs (located near the top of the Y-axis) to cycle the Y axis between Concentration versus Time, ln(concentration) versus Time and 1/concentration versus Time.

19. You may wish to use Experiments Options to save your experiment.

Model 1 – Collecting Kinetics Data

Model 1 Graph for the crystal violet and sodium hydroxide reaction

CALIBRATE DARK

CALIBRATE REFERENCE

START RECORDING

STOP RECORDING

EXPERIMENT OPTIONS

ANALYZE SOLUTION

CONCENTRATION

TIME

SCALE TO FIT

ADD COORDINATE

SHOW LINEAR FIT

SHOW COMPARISON

SHOW SELECTION

SHOW DUAL Y-AXES

QUICK CALCS

Analyzing Model 1 – Collecting Kinetics Data

20. Sketch or attach a copy of your graph of concentration versus time. Use the Show Selection tool to select better data if your concentration gets so close to zero that it starts to fluctuate. Can you, by visual inspection alone, determine the order of the reaction with respect to crystal violet? Why or why not?
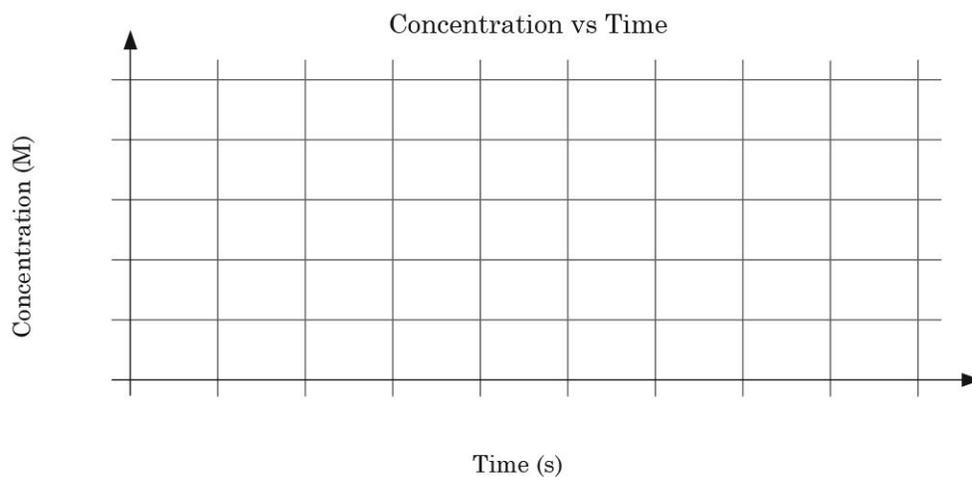
Concentration vs Time

Concentration (M)

Time (s)

_____

_____

21. Graph the ln(concentration) versus time. Does this appear to be a straight line?

ln(Concentration) vs Time

ln(Concentration)

Time (s)

_____

_____
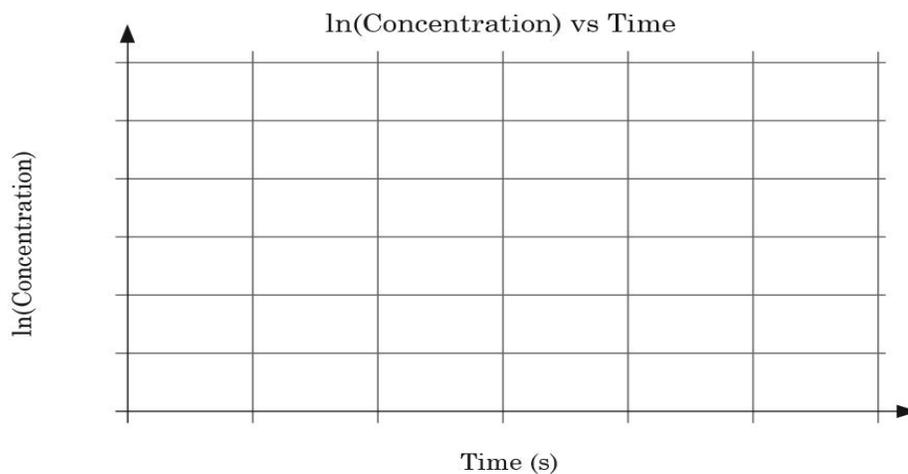
22. Graph the inverse of the concentration versus time. Does this appear to be a straight line?

1/(Concentration) vs Time

Time (s)

_____

_____
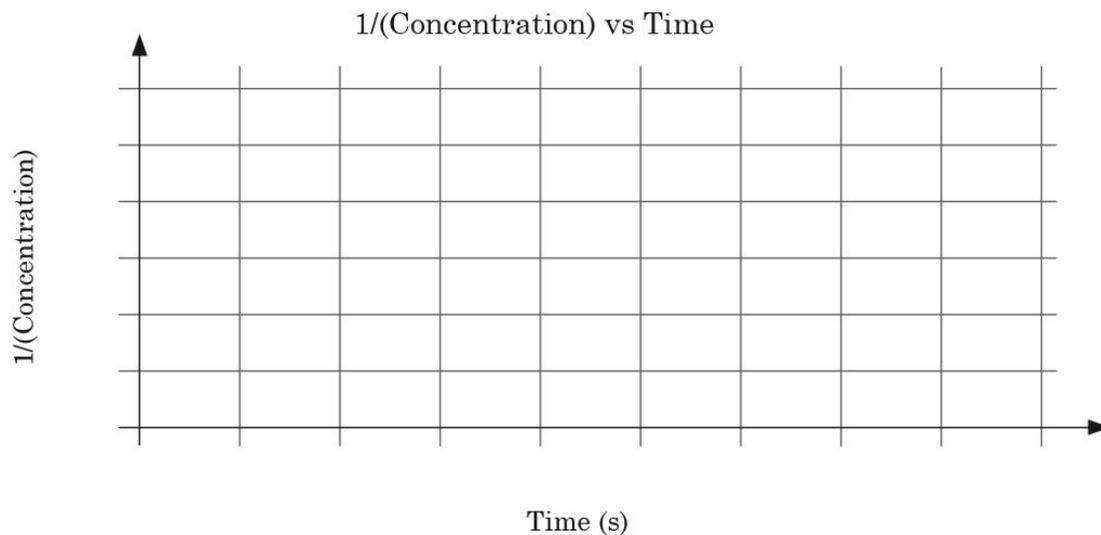
23. Based on the line of best fit for the most linear graph, what is the value of the rate constant k for this reaction?

_____

24. Based on your answer to the previous question, write the integrated rate law for the crystal violet (CV) + sodium hydroxide reaction.

25. Based on your equation and the value of k, at what time after the reaction started would the concentration drop from the initial concentration of 5.0×10^{-6} M to 5.0×10^{-7} M?

26. How does temperature affect the rate of a reaction? Does the temperature of the experiment appear in the integrated rate law?

_____

_____

MODEL 2

Building Model 2 – Testing the Effect of Temperature on the Rate Constant

In this model, create an experiment in which you determine if the rate law and rate constant are affected by the temperature.

A few things to think about: What are appropriate (and safe) temperatures to use? Will using temperatures 10°C apart be sufficient to tell if there is an effect? Will your data be more definitive if you choose a larger temperature range or a shorter range? How will you raise or lower the temperature of your solution from room temperature? How will you know the temperature of your solutions?

Conduct measurements using at least two different temperatures.

Use the Show Selection tool to select better data if your absorbance gets so close to zero that it starts to fluctuate.

Collect and analyze the data on the data collection system. When you finish, draw sketches of your most linear graphs that show how the rate law and rate constant are affected by temperature.

Model 2 – Testing the Effect of Temperature on the Rate Constant

Model 2 Graphs of reactions carried out at different temperatures
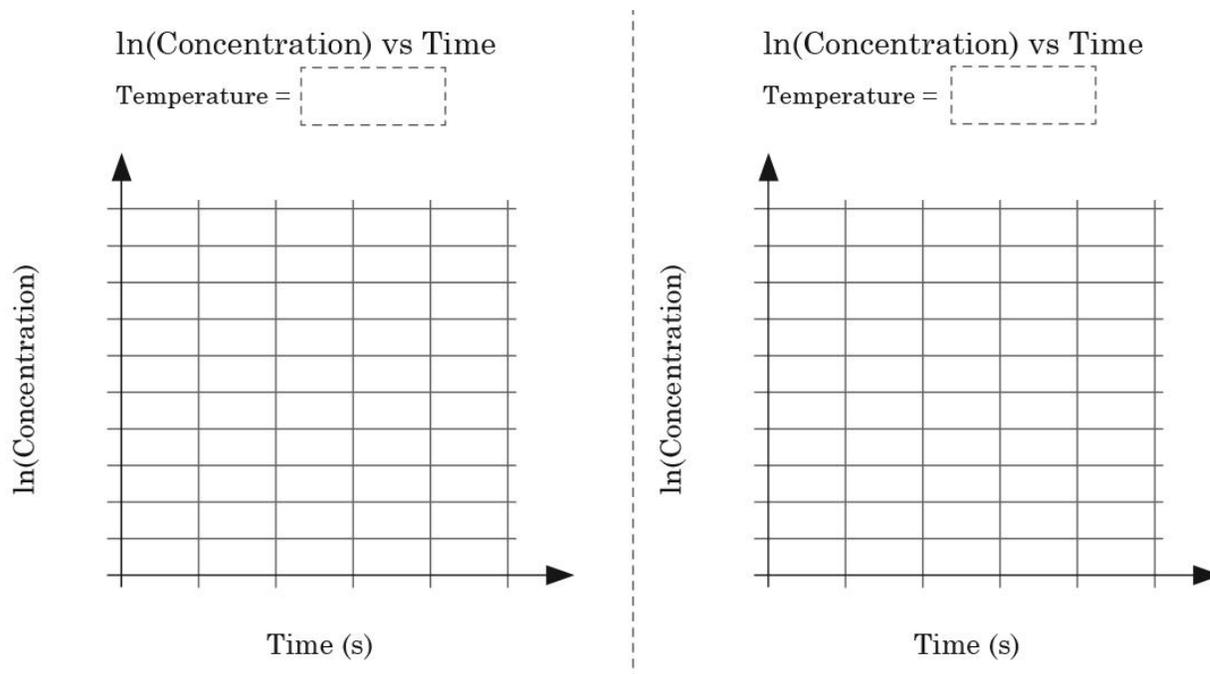
Analyzing Model 2

1. Which temperature caused the fastest reaction?

_____

2. Which temperature produced the greatest slope?

_____

3. What is the rate law constant for each temperature?

_____

_____

4. Is the rate constant affected by temperature?

_____

_____

Connecting to Theory

Svante Arrhenius suggested that chemical reactions need energy to get started. This energy is required to break bonds and align particles so that they are in the proper orientation for new bonds to form in the products. This energy is called the *activation energy* and is symbolized as E_a.

He realized that to calculate the Activation Energy, the reaction would have to be performed at two different temperatures, T. It would also require two rate constants, k_1 *and* k_2 that corresponds to the temperatures. His equation is listed below.
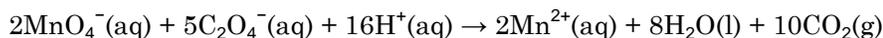
$$\ln\left(\frac{k_2}{k_1}\right) = \left(\frac{E_a}{R}\right)\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

The R in the equation is the gas constant, $8.31\frac{J}{K\ mol}$.

Calculate the activation energy from your data in Model 2.

Applying Your Knowledge

Consider the redox reaction between potassium permanganate and sodium oxalate. The net ionic reaction is

$$2MnO_4^-(aq) + 5C_2O_4^-(aq) + 16H^+(aq) \rightarrow 2Mn^{2+}(aq) + 8H_2O(l) + 10CO_2(g)$$

This reaction is used to titrate for oxalate, but for that purpose it is conducted at 60 °C, where it reacts very quickly. At room temperature the reaction is slow and the kinetics can be measured. However, the potassium permanganate is too dark at the relevant concentrations to measure the reaction progression with spectroscopy. Suggest what sensor (or sensors) you might use instead to measure this reaction. What might the data you collect from that sensor look like?

_____

_____

_____

Time (s)