EXPERIMENT 23

A Study of Reaction Rates

Performance Goal

23–1 State qualitatively and demonstrate experimentally the relationship between the rate of a chemical reaction and (a) temperature, (b) reactant concentration, and (c) the presence of a catalyst.

CHEMICAL OVERVIEW

The word *rate* implies change and time—change in some measurable quantity and the interval of time over which the change occurs. Speed in miles per hour, salary in dollars per month, and quantity in gallons per minute all express the idea of rate. The rate of a chemical reaction tells us how fast a reactant is being consumed or a product is being produced. Specifically, rate of reaction is the positive quantity that denotes how the concentration of a species in the reaction changes with time. For example, in the reaction

$$N_2(g) + 3\,H_2(g) \rightarrow 2\,NH_3(g) \qquad (23.1)$$

the rate of reaction can be expressed in terms of NH_3:

$$\text{Rate} = \frac{\text{change in concentration of } NH_3}{\text{time interval}} \qquad (23.2)$$

Alternatively, the rate could be expressed in terms of a reactant:

$$\text{Rate} = -\frac{\text{change in concentration of } N_2}{\text{time interval}} \qquad (23.3)$$

The minus sign is necessary to make the rate a positive quantity since the concentration of N_2 is decreasing with time.

The rate of a chemical reaction can be changed by (a) varying the concentration of reactants, (b) changing the temperature, or (c) introducing a catalyst.* In this experiment, you will study the effect of concentration by varying the concentration of one reactant while holding others constant, you will examine the rates of the same reaction at different temperatures, and you will conduct two reactions that will be identical in all respects except that a catalyst will be present in one and not in the other.

* Catalysts are substances that drastically alter reaction rates without being used up in the reaction.

In analyzing the results of this experiment, *time* of reaction will be used as an indication of rate. Time and rate are inversely related: the higher the rate, the shorter the time. This is evident if you think of driving from one location to another: it takes less time if you drive at a higher rate (speed).

The principal reaction whose rate will be studied in this experiment is the iodine ''clock reaction.'' It is the reaction between two solutions, solution A and solution B, that contain, among other things, an iodide and soluble starch. When the two solutions are combined, a series of reactions begins, ending with the release of elemental iodine. The appearance of iodine in the presence of starch may be detected easily by the appearance of a deep blue color. This signals the completion of the reaction.

SAFETY PRECAUTIONS AND DISPOSAL METHODS

Sulfuric acid can cause severe burns when in contact with skin. If you should spill any of the 6 M acid on yourself, *immediately* wipe it off with a dry cloth or paper towel and then rinse it off with large amounts of water. Wear safety goggles when performing this experiment. Beware that sulfuric acid generates a lot of heat when it comes in contact with water.

Solutions obtained in this experiment can be poured down the drain.

PROCEDURE

1. Comparison of Reaction Rates

Sodium Oxalate and Potassium Permanganate

A. Place about 15 mL of 0.1 M sodium oxalate, $Na_2C_2O_4$, into a large test tube and add 2 dropperfuls of 6 M sulfuric acid, H_2SO_4.

B. Place in a second test tube an amount of deionized water equal to the total volume of solution in the first test tube. This will be used as a control, or a color standard with which to compare the test tube in which the reaction is taking place.

C. Add 8 drops of 0.1 M potassium permanganate, $KMnO_4$, to the control test tube and mix by stirring. Place the test tube in a test-tube rack.

D. Recording the time to the nearest second, add 8 drops of 0.1 M potassium permanganate to the sodium oxalate solution and mix by stirring. Place the test tube in the rack, and observe the gradual color change compared to the control test tube. Record the time in seconds at which the reaction is complete, shown by the solution becoming colorless (not tan). Proceed to the next step while you are waiting.

The Iodine Clock Reaction

E. Using your graduated cylinder, pour 10 mL of solution A into a test tube. Rinse your graduated cylinder with deionized water and pour into it 10 mL of solution B.

F. Place a small beaker on a piece of white paper. Noting the time of mixing to the nearest second, pour the two solutions simultaneously into the beaker. Record the time to the nearest second when you observe the first sign of a reaction, shown by the appearance of a dark blue color.

2. Effect of Concentration

To study the effect of concentration on the reaction rate, you will keep total volume, concentration of solution A, and temperature constant, and vary only the concentration of solution B.

A. Pour 10 mL of solution A into each of four test tubes, as you did into one test tube in Step 1E. Place the test tubes into a test-tube rack. Rinse your cylinder with deionized water.

B. Label four other test tubes 1 to 4 and place them into the test-tube rack. Using a 10-mL graduated cylinder, pour into each test tube the quantities of deionized water and solution B shown in the following table:

Test Tube Number	*Volume of Deionized Water (mL)*	*Volume of Solution B (mL)*	*Total Volume (mL)*
1	2	8	10
2	4	6	10
3	6	4	10
4	8	2	10
Part 1E	0	10	10

The undiluted solution B used in Steps 1E and 1F is added to the table for comparison. Note that the test tube from 1E has the highest concentration of solution B, test tube number 1 the next highest, and test tube number 4 the lowest. Note also that the total volume is the same in each case.

C. As in Step 1F, at some time 0 on a watch, pour the solution from test tube number 1 and the solution A from one of the four test tubes simultaneously into a small beaker on a piece of white paper. Record the number of seconds required for the reaction. Empty the beaker and rinse it with deionized water. Repeat the procedure with the remaining test-tube combinations, recording the elapsed time in each case.

3. Effect of Temperature

A. Using a graduated cylinder, measure 10 mL of solution A into each of four test tubes. Rinse the cylinder, and then measure 10 mL of solution B into each of four other test tubes. Measure and record the temperature of solution A in one of the test tubes. (We will assume that solution B is at the same temperature, which is room temperature.) As before, empty one test tube of solution A and one test tube of solution B simultaneously into a small beaker. Record the time required for the reaction. (This is a repeat of Step 1F, except that this time you have recorded the temperature of the reactants.)

B. Place a test tube of solution A and a test tube of solution B into a 250-mL beaker containing tap water and a few chunks of ice. Immerse a thermometer into the test tube containing solution A. Be sure not to let the thermometer rest on the bottom of the test tube. (Again, we will assume that solution B, treated in the same manner as solution A, will have the same temperature.) Stir the contents of the beaker with the test tubes. When the temperature drops to about 10°C below room temperature, remove both test tubes from the ice bath and immediately pour the two solutions into a beaker, as before. Record both the temperature of the solutions and the time of the reaction.

C. Repeat the above procedure, replacing the ice-water bath with warm tap water. When the temperature of solution A has risen about 10°C above room temperature, pour the two solutions together. Obtain one more reading at about 20°C above room temperature. For each reading, record the solution temperature and the reaction time on the work page.

4. Effect of a Catalyst

Measure 10 mL of solution A into a test tube and add a drop of 0.1 M copper(II) sulfate, $CuSO_4$, catalyst. In another test tube, combine 2 mL of solution B and 8 mL of deionized water (the same procedure as in Part 2, test tube number 4). Pour the solutions simultaneously into a beaker and record the time required for the reaction.

RESULTS

Part 2. Using the graph paper provided, plot a graph of milliliters of solution B divided by total milliliters versus reaction time (use two significant figures). What relationship seems to be evident between concentration of solution B and the time needed for the blue color to appear?

Part 3. Using the graph paper provided, plot a graph of temperature versus reaction time.

Part 4. Compare the reaction times of the catalyzed reaction (Part 4) and the uncatalyzed reaction (Part 2, test tube 4) of solutions of the same concentration. How does the time required for the blue color to appear in this step compare with the time you observed for test tube number 4 in Part 2? Record your comparison on the work page.

Name *Date* *Section*

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Advance Study Assignment

1. Name two variables that affect reaction rates.

2. What is a catalyst?

3. Give an everyday example of how temperature alters reaction rates.

______________________________ ____________ ____________
Name *Date* *Section*

Experiment 23

Work Page

Part 1—Comparison of Reaction Rates

	Sodium Oxalate + Potassium Permanganate	*Iodine Clock Reaction*
Time reaction began		
Time reaction completed		
Time of reaction (sec)		

Reaction having higher rate: Sodium oxalate + potassium permanganate ______________; iodine clock reaction ______________.

Part 2—Effect of Concentration on the Iodine Clock Reaction

Test Tube	$\frac{\textit{Volume of Solution B}}{\textit{Total Volume}}$	*Time (sec)*
1		
2		
3		
4		

Reaction rate varies directly ____________, inversely ____________ with concentration of solution B.

Part 3—Effect of Temperature on the Iodine Clock Reaction

Temperature (°C)	*Time (sec)*

Increasing the temperature increases __________, decreases __________ the reaction rate.

Part 4—Effect of a Catalyst on the Iodine Clock Reaction

Reaction	*Time (sec)*
Without catalyst (test tube number 4, Part 2)	
With catalyst (from Part 4)	

Which *reaction rate* is greater? Catalyzed _______________; uncatalyzed _______________.

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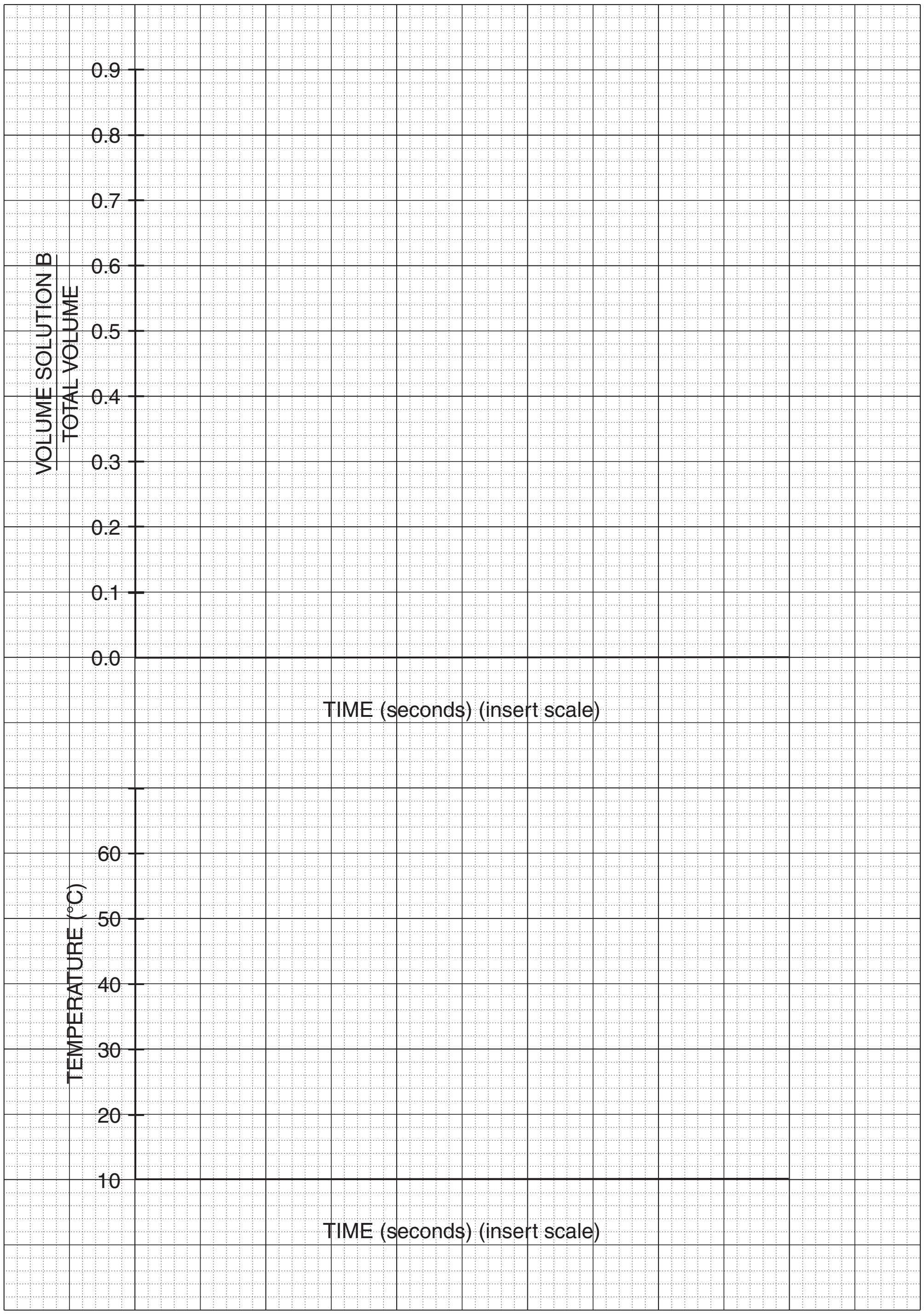
Work Page



Name ______________________ Date ____________ Section ____________

Experiment 23

Report Sheet

Part 1—Comparison of Reaction Rates

	Sodium Oxalate + Potassium Permanganate	*Iodine Clock Reaction*
Time reaction began		
Time reaction completed		
Time of reaction (sec)		

Reaction having higher rate: Sodium oxalate + potassium permanganate ______________; iodine clock reaction __________.

Part 2—Effect of Concentration on the Iodine Clock Reaction

Test Tube	$\frac{\textit{Volume of Solution B}}{\textit{Total Volume}}$	*Time (sec)*
1		
2		
3		
4		

Reaction rate varies directly __________, inversely __________ with concentration of solution B.

Part 3—Effect of Temperature on the Iodine Clock Reaction

Temperature (°C)	*Time (sec)*

Increasing the temperature increases ______________, decreases ______________ the reaction rate.

Part 4—Effect of a Catalyst on the Iodine Clock Reaction

Reaction	*Time (sec)*
Without catalyst (test tube number 4, Part 2)	
With catalyst (from Part 4)	

Which *reaction rate* is greater? Catalyzed ______________; uncatalyzed ______________.

1. State the meaning of the term ''reaction rate.''
2. What is a catalyst?
3. If you wanted to alter the rate of a chemical reaction, what changes would you make in the experimental conditions?

Name | Date | Section

Experiment 23

Report Sheet