Rate of Reaction of Sodium Thiosulfate and Hydrochloric Acid

Rate Laws

Introduction

The purpose of this demonstration is to investigate the effect of sodium thiosulfate concentration on the rate of reaction of sodium thiosulfate with hydrochloric acid. The reaction, which produces solid sulfur, will be followed by measuring the time needed for the reaction mixture to become opaque. The results will be analyzed graphically to determine the order of reaction—the mathematical relationship between the reactant concentration and the rate.

Concepts

- Kinetics
- Order of reaction
- Rate law
- Concentration

Materials

Hydrochloric acid solution, HCl, 2 M, 25 mL
Sodium thiosulfate solution, $Na_2S_2O_3$, 0.15 M, 150 mL
Distilled or deionized water
Beakers, 100-mL, 5
Graduated cylinders, 50- or 100-mL, 2
Graduated cylinders, 10-mL, 5
Overhead projector or light box
Permanent marker
Stirring rods
Stopwatch or timer

Safety Precautions

Hydrochloric acid solution is corrosive to eyes and skin. It is moderately toxic by ingestion and inhalation. Sodium thiosulfate solution is a body tissue irritant. The reaction of sodium thiosulfate and hydrochloric acid generates sulfur dioxide gas, which is a skin and eye irritant. Perform this demonstration in a well-ventilated lab only. Avoid contact of all chemicals with eyes and skin. Wear chemical splash goggles, temperature-resistant gloves, and chemical-resistant apron. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Procedure

1. Label five 100-mL beakers 1–5 and clean the bottom of each beaker.
2. Draw a large "X" across the bottom on the outside of each beaker. Place the beakers on an overhead projector stage or a light box so that students can view the "X."
3. Using separate graduated cylinders for the solution and water, measure and add the required amounts of 0.15 M sodium thiosulfate and distilled water to each beaker. Be as precise as possible.

Beaker	**1**	**2**	**3**	**4**	**5**
0.15 M $Na_2S_2O_3$	50.0 mL	40.0 mL	30.0 mL	20.0 mL	10.0 mL
Distilled Water	0 mL	10.0 mL	20.0 mL	30.0 mL	40.0 mL

4. Have students calculate the final concentration of sodium thiosulfate in each beaker 1–5.
5. Record the following information in a data table: Beaker, volume of $Na_2S_2O_3$ solution, volume of distilled water, concentration of $Na_2S_2O_3$, reaction time (sec), and 1/reaction time (reaction rate). See the Sample Data and Results table in the *Discussion* section.
6. Measure 5.0 mL of 2 M hydrochloric acid into each of five 10-mL graduated cylinders.

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7. Starting with beaker #1, carefully add the HCl all in one pour to the sodium thiosulfate solution. Stir the solution once with a stirring rod and immediately start timing.
8. Stop timing when the black "X" is no longer visible. Record the reaction time in seconds in the data table.
9. Repeat steps 7 and 8 with beakers 2–5.
10. Calculate 1/reaction time for each trial. Plot concentration vs. time and concentration vs. 1/time on separate graphs.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. Collect the leftover reaction mixtures and filter to separate the solid sulfur product. The sulfur may be disposed of in a landfill according to Flinn Suggested Disposal Method #26a. The filtrate may be neutralized and disposed of down the drain with excess water according to Flinn Suggested Disposal Method #26b.

Tips

- This activity may be performed as a chemical demonstration with classroom participation or as a student activity. The contents of the beakers project well on an overhead projector and the time to the disappearance of the black "X" is easily seen and measured.
- The reaction may be downsized for a student lab activity. Carry out individual trials in separate wells in a 6-well reaction plate or in small medicine cups. If students will be doing the experiment in the lab, it is a good idea for them to start with beaker #5, because it takes the longest time.
- The activity may also be performed as a cooperative class exercise with different groups investigating different variables, including the effect of HCl concentration and the effect of temperature. The reaction rate is zero-order with respect to HCl.
- Empty the beakers and clean them thoroughly using paper towels to remove the sulfur. If the colloidal sulfur is allowed to sit in the beakers for an extended time, it will be much more difficult to remove the deposits from the glass.
- To achieve better mixing of the reactants, add the hydrochloric acid using a 10-mL luer-lock plastic syringe (without needle). Squirt the acid using a fair amount of force.
- When lower concentrations of sodium thiosulfate are used, the rate law does not appear to be as simple as predicted in this experiment. At lower concentrations, the reaction appears to be closer to 3/2-order in sodium thiosulfate and 1/2-order in hydrochloric acid. The reaction time is more difficult to measure at lower concentrations because the onset of turbidity is more gradual.
- Both the overall chemical equation and the mechanism for the decomposition of sodium thiosulfate are more complex than suggested by Equation 1. The reaction is acid-catalyzed, which means that the acid concentration must have some bearing on the rate in terms of producing an equilibrium concentration of $HS_2O_3^-$ ions, The $HS_2O_3^-$ ion is a reactive intermediate, reacting further with additional $S_2O_3^{2-}$ ions to produce polymeric ions containing multiple S atoms. When the chain of S atoms in a polymeric ion becomes long enough, it "closes" in on itself to form a ring of elemental sulfur (S_8).

$$S_2O_3^{2-} + H^+ \rightleftharpoons HS_2O_3^-$$

$$H\text{—}S\text{—}SO_3^- + nS_2O_3^{2-} \rightarrow H\text{—}S\text{—}(S)_n\text{—}SO_3^- + nSO_3^{2-}$$

$$H\text{—}S\text{—}S_n\text{—}SO_3^- \rightleftharpoons H^+ + {}^-S\text{—}S_n\text{—}SO_3^-$$

$${}^-S\text{—}S_7\text{—}SO_3^- \rightarrow S_8 + SO_3^{2-}$$

Discussion

Sodium thiosulfate reacts with hydrochloric acid to form sulfur and sulfur dioxide (Equation 1).

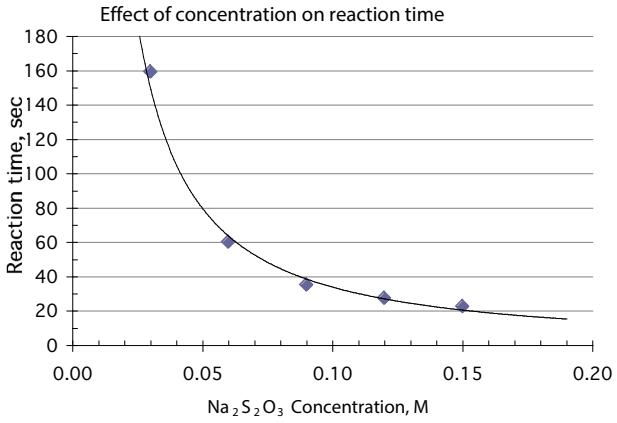
$$Na_2S_2O_3(aq) + 2HCl(aq) \rightarrow S(s) + SO_2(g) + 2NaCl(aq) \qquad \textit{Equation 1}$$

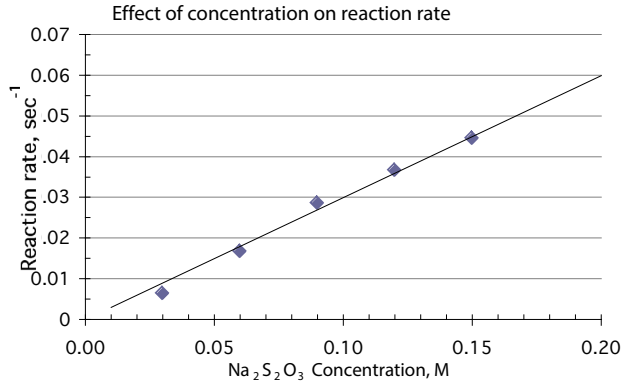
The kinetics of the reaction can be analyzed by graphing the concentration of $Na_2S_2O_3$ as a function of both reaction time and 1/time. A plot of concentration versus time gives a curved line, which levels off as it approaches the x-axis—the reaction slows down as the reactant concentration decreases. The rate of a reaction is inversely proportional to reaction time. A plot of

concentration of versus 1/time gives a straight line. The rate is directly proportional to concentration, and the reaction appears to be first order with respect to sodium thiosulfate concentration.

Sample Data and Results

Beaker	Volume of $Na_2S_2O_3$ (mL)	Volume of H_2O (mL)	$[Na_2S_2O_3]$, M	Reaction time (sec)	Reaction rate (1/time, sec^{-1})
1	50	0	0.15	22.5	.0444
2	40	10	0.12	27.3	.0367
3	30	20	0.090	35.1	.0285
4	20	30	0.060	60.0	.0167
5	10	40	0.030	159.1	.00629





Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Constancy, change, and measurement
Content Standards: Grades 9–12
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, structure and properties of matter, chemical reactions, motions and forces

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Rate of Reaction of Sodium Thiosulfate and Hydrochloric Acid* activity, presented by Annis Hapkiewicz, is available in *Rate Laws*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Rate of Reaction of Sodium Thiosulfate and Hydrochloric Acid* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Reaction Order and Rate Laws—Student Laboratory Kit* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP4864	Reaction Order and Rate Laws—Student Laboratory Kit
H0034	Hydrochloric Acid, 3 M, 500 mL
S0114	Sodium Thiosulfate Pentahydrate, Reagent, 500 g
AP1572	Timer, Stopwatch, Flinn
GP1010	Beaker, Borosilicate Glass, 100 mL
GP2005	Graduated Cylinder, Borosilicate Glass, 10-mL
GP2015	Graduated Cylinder, Borosilicate Glass, 50-mL

Consult the Flinn Scientific website for current prices.