Lab 29. Rate Laws: What Is the Rate Law for the Reaction Between Hydrochloric Acid and Sodium Thiosulfate?

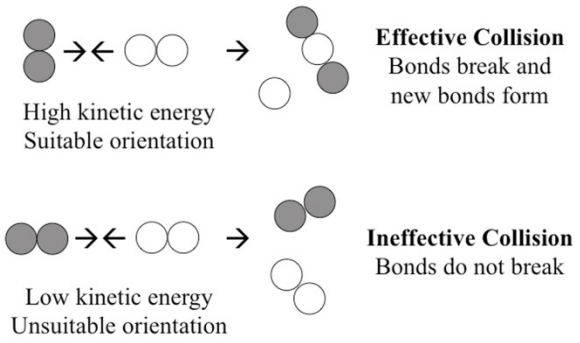
Introduction

The *collision theory of reactions* suggests that the rate of a reaction depends on three important factors. The first is the number of collisions that take place between molecules during a reaction. This factor is important because molecules must collide with each other for a reaction to take place. The second factor is the average energy of these collisions. This factor is important because colliding molecules must have enough kinetic energy to overcome the repulsive and bonding forces of the reactants. The minimum amount of energy needed for the reactants to transform into products is called the *activation energy* of the reaction. The third, and final, factor is the orientation of the molecules at the time of the collision. This factor is important because the reactant molecules must collide with each other in a specific orientation for the atoms in these molecules to rearrange (see Figure L29.1). Chemists can therefore alter the rate of a specific chemical reaction by manipulating one or more of these factors inside the laboratory.

Chemists, for example, can change the temperature of the reactants to speed up or slow down a reaction. Temperature affects the rate of a reaction because the proportion of molecules with enough kinetic energy to overcome the activation energy barrier of a reaction goes up when the temperature increases and goes down when temperature decreases. Chemists can also change the concentration of the reactants to speed up or slow down the rate of a reaction. A change in reactant concentration changes the frequency of collisions between molecules but does not affect the likelihood that any given collision between any two molecules will be effective and result in a reaction. The likelihood of an effective collision, as noted earlier, depends on how much kinetic energy the molecules have and the orientation of the molecules when they collide with each other.

FIGURE L29.1

The collision theory of reactions



Chemists use an equation called a rate law to describe how the concentration of each reactant affects the overall reaction rate. For a general reaction of the form A + B → C, the rate law is written as

$$Rate = k[A]^n[B]^m$$

In this equation, k is the rate constant, [A] is the molar concentration of the reactant A, [B] is the molar concentration of the reactant B, and the exponents n and m define how the reaction rate depends on the concentration of each reactant. The rate constant for a reaction is affected by temperature but not by concentration. The n and m exponents are often described as the reaction order. In this example, the reaction is to the nth order of A and the mth order of B. Typical values of n and m are 0, 1, or 2.

The reaction order for each reactant in the rate law indicates how much the reaction rate will change in response to a change in the concentration of each reactant. If a reactant has an order of 0, then the reaction rate is not affected by the concentration of this reactant. Reactants with an order of 0 are therefore not included in the rate law. When a reactant has an order of 1, the change in reaction rate is directly proportional to the change in reactant concentration. The rate of a chemical reaction, for example, will double when the concentration of a first-order reactant is doubled and will triple when the concentration of the first-order reactant is tripled. When a reactant has an order of 2, the rate of reaction will change twice as

much as the change in the reactant concentration. The rate of a chemical reaction, for example, will quadruple when the concentration of a second-order reactant is doubled.

It is important for chemists to understand how changing the concentration of one or more reactants will affect the overall rate of a specific chemical reaction so they can make a specific product in a safe and time-efficient manner. Unfortunately, chemists cannot determine the reaction order for each reactant in a specific reaction by simply looking at a balanced chemical equation; they must determine it through a process called the *differential method*. This method allows chemists to determine a rate law by varying the concentration of the reactants in a reaction in a systematic manner and then measuring how these changes affect the reaction rate. A description of the differential method can be found in the Lab Reference Sheet (p. 470).

Your Task

Use the differential method to determine the rate law for the reaction between hydrochloric acid (HCl) and sodium thiosulfate ($Na_2S_2O_3$). The balanced chemical equation for this reaction is

$$2HCl(aq) + Na_2S_2O_3(aq) \rightarrow S(s) + SO_2(aq) + H_2O(l) + 2NaCl(aq)$$

The guiding question of this investigation is, **What is the rate law for the reaction between hydrochloric acid and sodium thiosulfate?**

Materials

You may use any of the following materials during your investigation:

Consumables	Equipment
• M HCl • 0.3 M $Na_2S_2O_3$ • Distilled water	• 2 6-well reaction plates • 3 beakers (each 50 ml) • 3 graduated cylinders (each 10 ml) • 3 disposable pipettes • Stopwatch or timer

Safety Precautions

Follow all normal lab safety rules. Hydrochloric acid is moderately toxic by ingestion and inhalation, and it is also corrosive to the eyes and skin. Sodium thiosulfate is a body tissue irritant. The sulfur precipitate and aqueous sulfur dioxide, which are products of the reaction between hydrochloric acid and sodium thiosulfate, are skin and eye irritants. Your teacher will explain relevant and important information about working with the chemicals associated with this investigation. In addition, take the following safety precautions:

- Wear indirectly vented chemical-splash goggles and chemical-resistant gloves and apron while in the laboratory.
- Handle all glassware with care.
- Wash your hands with soap and water before leaving the laboratory.

Investigation Proposal Required? ☐ Yes ☐ No

Getting Started

The first step in the differential method is to carry out two experiments. The goal of the first experiment is to determine how a change in concentration of hydrochloric acid affects the reaction rate. The goal of the second experiment is to determine how a change in the concentration of sodium thiosulfate affects reaction rate. In each of your experiments, you will be able to measure reaction time by monitoring the appearance of the sulfur precipitate. The solution will change from clear to cloudy over time.

You will need to mix the reactants together in different concentrations in each of your experiments. You can change the concentration of each reactant by changing the amount of reactant you add to a well in a well plate. You can add between 1 and 4 ml of a reactant to a well, but the total volume of liquid added to each well should always equal 5 ml to keep volume constant across conditions. You can use

water to bring the total volume of the liquid in a well up to 5 ml. For example, if you add 1 ml of HCl to 3 ml of $Na_2S_2O_3$, you will need to add 1 ml of water to bring the total volume of liquid in the well up to 5 ml. If you add 2 ml of HCl to 3 ml of $Na_2S_2O_3$, you will not need to add any water because the total volume of the liquid in the well is already 5 ml. Keep this information in mind as you design your two experiments. You will also need to determine what type of data you need to collect, how you will collect the data, and how you will analyze the data.

To determine *what type of data you need to collect*, think about the following questions:

- What types of measurements or observation will you need to make during each experiment?
- When will you need to make these measurements or observations?

To determine *how you will collect the data*, think about the following questions:

- What will serve as your independent variable in each experiment?
- What will serve as your dependent variable in each experiment?
- What comparisons will you need to make in each experiment?
- How will you determine when a reaction is finished?
- How will you hold other variables constant across each comparison?
- What will you do to reduce measurement error?
- How will you keep track of the data you collect and how will you organize it?

To determine *how you will analyze the data*, think about the following questions:

- How will you determine the concentration of each reactant at the beginning of the reaction?
- What type of calculations will you need to make?
- What type of graph could you create to help make sense of your data?

The second step in this investigation is to determine the rate law for this reaction. To determine the rate law, you will need to first calculate the reaction order for each reactant using the data you collected in each experiment. The Lab Reference Sheet describes how to make these calculations. Next, you will need to calculate the value of k for the rate law. To calculate the rate constant, you simply need to substitute the appropriate values for the concentration of each reactant, the reaction order for each reactant, and the reaction rate into the rate law equation and solve for *k*.

The third and final step in the investigation is to test your rate law. To accomplish this task, you will need to determine if you can use your rate law to make accurate predictions about reaction times. If you can use the rate law you developed to make accurate predictions about the time it takes for the sulfur precipitate to appear when using different concentrations of hydrochloric acid and sodium thiosulfate, then you will have evidence that suggests that the rate law you developed is a valid one.

Connections to Crosscutting Concepts, the Nature of Science, and the Nature of Scientific Inquiry

As you work through your investigation, be sure to think about

- why it is important to look for and use proportional relationships;
- why it is important to track how energy and matter move into, out of, and within systems;
- the difference between observations and inferences in science; and
- the difference between laws and theories in science.

Initial Argument

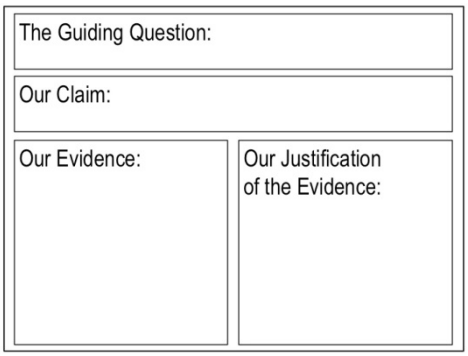
Once your group has finished collecting and analyzing your data, you will need to develop an initial argument. Your argument must include a *claim*, which is your answer to the guiding question. Your argument must also include *evidence* in support of your claim. The evidence is your analysis of the data and your interpretation of what the analysis means. Finally, you must include a *justification* of the evidence in your argument. You will therefore need to use a scientific concept or principle to explain why the evidence that you decided to use is relevant and important. You will create your initial argument on a whiteboard. Your whiteboard must include all the information shown in Figure L29.2.

Argumentation Session

The argumentation session allows all of the groups to share their arguments. One member of each group stays at the lab station to share that group's argument, while the other members of the group go to the other lab stations one at a time to listen to and critique the arguments developed by their classmates. The goal of the argumentation session is not to convince others that your argument is the best one; rather, the goal is to identify errors or instances of faulty reasoning in the initial arguments so these mistakes can be fixed. You will therefore need to evaluate the content of the claim, the quality of the evidence used to support the claim, and the strength of the justification of the evidence included in each argument that you see. To critique an argument, you might need more information than what is included on the whiteboard. You might, therefore, need to ask the presenter one or more follow-up questions, such as:

FIGURE L29.2

Argument presentation on a whiteboard



- How did your group collect the data? Why did you use that method?
- What did your group do to make sure the data you collected are reliable? What did you do to decrease measurement error?
- What did your group do to analyze the data, and why did you decide to do it that way? Did you check your calculations?
- Is that the only way to interpret the results of your group's analysis? How do you know that your interpretation of the analysis is appropriate?
- Why did your group decide to present your evidence in that manner?
- What other claims did your group discuss before deciding on that one? Why did you abandon those alternative ideas?
- How confident are you that your group's claim is valid? What could you do to increase your confidence?

Once the argumentation session is complete, you will have a chance to meet with your group and revise your original argument. Your group might need to gather more data or design a way to test one or more alternative claims as part of this process. Remember, your goal at this stage of the investigation is to develop the most valid or acceptable answer to the research question!

Report

Once you have completed your research, you will need to prepare an *investigation report* that consists of three sections that provide answers to the following questions:

- What question were you trying to answer and why?
- What did you do during your investigation and why did you conduct your investigation in this way?
- What is your argument?

Your report should answer these questions in two pages or less. The report must be typed and any diagrams, figures, or tables should be embedded into the document. Be sure to write in a persuasive style; you are trying to convince others that your claim is acceptable or valid!