# Lab 21. Reaction Rates: Why Do Changes in Temperature and Reactant Concentration Affect the Rate of a Reaction?

## Introduction

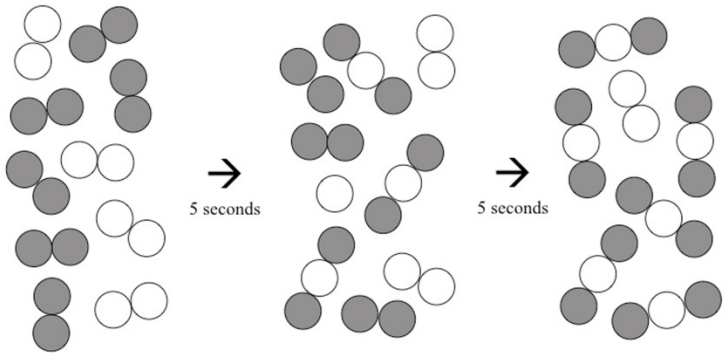
The molecular-kinetic theory of matter suggests that all matter is made up of submicroscopic particles called atoms that are constantly in motion. These atoms can be joined together to form molecules. Atoms have kinetic energy because they move and vibrate. The more kinetic energy an atom has, the faster it moves or vibrates. *Temperature* is a measurement of the average kinetic energy of all the atoms in a substance. The average kinetic energy of the particles within a substance increases and decreases as it changes temperature. *Heat*, in contrast, is the total kinetic energy of all the particles in a substance.

A chemical reaction, as you have learned, is simply the rearrangement of atoms. The substances (elements and/or compounds) that are changed into other substances during a chemical reaction are called *reactants*. The substances that are produced as a result of a chemical reaction are called *products*. Chemical equations show the reactants and products of a chemical reaction. A chemical equation includes the chemical formulas of the reactants and the products. The products and reactants are separated by an arrow symbol (→), and the chemical formula for each individual substance is separated by a plus sign (+).

A balanced chemical equation tells us the nature of the products and the amount of product that is formed from a given amount of reactants. A balanced chemical equation, however, tells us little about how long it takes for the reaction to happen. Some chemical reactions, such as the rusting of iron, happen slowly over time, while others, such as the burning of gasoline, are almost instantaneous. The speed of any reaction is indicated by its *reaction rate*, which is a measure of how quickly the reactants transform into products. As shown in Figure L21.1, a reaction begins with only reactant molecules. Over time, the reactant molecules interact with each other and form product molecules. The concentration of reactant molecules and the product molecules, as a result, will change during the process of a reaction. The rate of a reaction can therefore be calculated by measuring how the concentration of the reactants decreases or the concentration of the products increases as a function of time. The rate of a reaction can also be measured by timing how long it takes for a product to appear or for a reactant to disappear once the reaction begins

FIGURE L21.1

**A model of what happens during a chemical reaction over time**




It is important for chemists to understand how and why different factors affect the rate of a chemical reaction so they can make a wide range of products in a safe and economical manner. You will therefore explore two factors that affect the rate of a specific reaction and then develop a conceptual model that you can use to explain your observations and predict the rate of this reaction under different conditions.

## Your Task

Determine how temperature and changes in the concentration of a reactant affect the rate of the reaction between magnesium (Mg) and hydrochloric acid (HCl). Then develop a conceptual model that can be used to explain *why* these factors influence reaction rate. Once you have developed your model, you will need to determine if it is consistent with the rates of reaction that you observe under other conditions.

The guiding question of this investigation is, **Why do changes in temperature and reactant concentration affect the rate of a reaction?**

## Materials

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

| Consumables | Equipment |
|---|---|
| • 2 pieces of 18-gauge copper wire (20 cm)<br>• Magnesium ribbon (30 cm)<br>• 3 M HCl<br>• 2 M HCl<br>• 1 M HCl<br>• 0.5 M HCl<br>• M HCl<br>• Ice | • 2 Pyrex test tubes<br>• Test tube rack<br>• Graduated cylinder (25 ml)<br>• 2 beakers (each 250 ml)<br>• Thermometer (or temperature probe)<br>• Hot plate<br>• Electronic or triple beam balance<br>• pH paper |

## Safety Precautions

Follow all normal lab safety rules. Magnesium is a flammable solid, and hydrochloric acid is a corrosive liquid. 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.
- Do not heat hydrochloric acid directly on a hot plate; rather, heat the hydrochloric acid using a hot bath and keep the temperature of the bath between 20°C and 60°C.
- Use caution when working with hot plates because they can burn skin. Hot plates also need to be kept away from water and other liquids.
- 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 developing your model is to design and carry out two experiments. The goal of the first experiment will be to determine how temperature affects reaction rate. The goal of the second experiment will be to determine how reactant concentration affects reaction rate. For these two experiments, you will focus on the reaction of magnesium and hydrochloric acid. These two chemicals react to form hydrogen gas and magnesium chloride. The equation for this reaction is

$$Mg(s) + 2HCl(aq) \rightarrow H_2(g) + MgCl_2(aq)$$

You can measure the reaction rate by simply timing how long it takes for the solid magnesium to be no longer visible once it is mixed with the hydrochloric acid. You can also measure the reaction rate by timing how long hydrogen gas is produced after the magnesium and hydrochloric acid are mixed. The unit of measurement for a reaction rate is mol/sec. It will therefore be important for you to determine how many moles of each reactant you used for each test.

To design your two experiments, you will need to decide 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:

- How will you determine the number of moles of each reactant at the beginning of the reaction?
- How will you know when the reaction starts and when it is finished?
- What type of measurements will you need to record 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:

- How much magnesium ribbon will you use in each test?

- How much hydrochloric acid will you need to use to submerge the magnesium ribbon?
- How will you prevent the magnesium ribbon from floating on top of the hydrochloric acid? One way to prevent the magnesium from floating on top of the hydrochloric acid is to use copper wire to create a cage (see Figure L21.2).
- What will serve as your independent variable?
- What types of comparisons will you need to make?
- How will you hold other variables constant?
- 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:

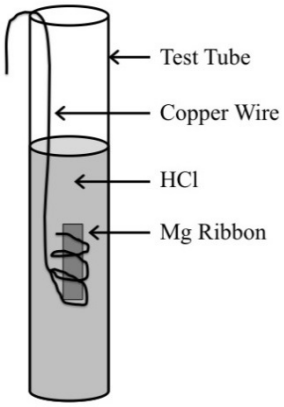
- What type of calculations will you need to make?
- What type of graph could you create to help make sense of your data?

Once you have carried out your two experiments, your group will need to develop a conceptual model. This conceptual model must provide an underlying reason for your findings about the effect of temperature and reactant concentration on reaction rate. Your model should also include an explanation of what is happening at the submicroscopic level between and within molecules during a reaction. The molecular-kinetic theory of matter should serve as the theoretical foundation for your model.

The last step in this investigation is to test your model. To accomplish this goal, you can use the same reaction but test different temperatures and concentrations to determine if your model is consistent with the rates of reactions you observe under different conditions. If you can use your model to make accurate predictions about the rate of this reaction under different conditions, then you will be able to generate the evidence you need to convince others that the conceptual model you developed is valid.

## FIGURE L21.2

**How to suspend magnesium (Mg) ribbon in the hydrochloric acid (HCl). The copper wire does not react with the HCl.**




## 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

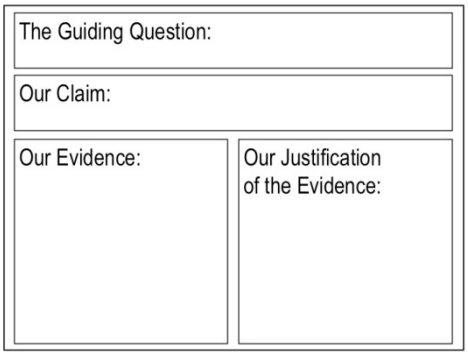
- the importance of developing causal explanations for observations,
- how models are used to help understand natural phenomena,
- the importance of imagination and creativity in science, and
- the role of experiments in science.

## 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 L21.3.

FIGURE L21.3

**Argument presentation on a whiteboard**




## 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:

- 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:

1. What question were you trying to answer and why?
2. What did you do during your investigation and why did you conduct your investigation in this way?
3. 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!