10. WHAT DOES ACID RAIN DO TO CORAL REEFS?

Introduction

Many factors affect how fast chemical reactions occur. One can imagine that these factors have significant implications in many industries, in all areas of science and engineering, and in art and architecture. A fast reaction rate is beneficial in certain circumstances such as gas production during the inflation of an automobile airbag. However, some reactions, such as the ones responsible for the destruction of coral reefs, could use a slowing down. In this lab, you will investigate the factors that affect reaction rates of calcium carbonate decomposition in the presence of acid. As calcium carbonate is a principal component of earth coral reefs, you will be able to correlate your observations with the effects of acid rain on the oceanic environment.

Concepts

- Kinetics
- Reaction rates
- Reaction order
- Gas laws
- Acid-base reactions
- Environmental chemistry

Background

More than 4% of the Earth's crust is made up of calcium carbonate, making it one of the most abundant minerals in nature. Its common forms, limestone and marble, have been used as major building materials throughout the world for over 5000 years. Calcium carbonate is also a principal structural mineral in coral and seashells. Acid rain and ocean acidification pose a great environmental danger to both aquatic and terrestrial ecosystems by accelerating the dissolution of calcium carbonate.

In this experiment, the dependence of calcium carbonate decomposition on hydrochloric acid concentration will be examined by measuring the production of carbon dioxide gas. The overall reaction is as follows:

$$\mathbf{CaCO_3(aq) + 2HCl(aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)}$$

The rate of CO2 gas production will be determined by measuring gas pressure as a function of time at various HCl concentrations. The rate of a reaction describes how fast the reaction occurs; that is, the faster the rate, the less time it will take to convert reactants to products.

Rate = Change in Gas Pressure/Time

The rate of a reaction and the concentration of reactants are correlated in a mathematical equation called the rate law. Thus, for the general reaction.

$$A + B \rightarrow C$$

the rate law can be written as : Rate = k[A]n[B]m where [A] and [B] represent reactant concentrations, k is the rate constant and n and m represent the orders of the reaction with respect to a reactant. Reaction order defines how the rate depends on the individual reactant concentrations and can only be determined experimentally. Over time, the rate of a reaction decreases as the concentration of reactants decreases. Thus, rate laws are typically determined by analyzing initial rates, when only 10-20% of reactants have been converted to product.

The purpose of this experiment is to examine the rate of decomposition of solid calcium carbonate as a function of varying concentrations of hydrochloric acid. Reaction rates will be determined by the measuring the pressure produced by carbon dioxide gas, a product of this heterogeneous reaction. The experiment will be conducted using special equipment in a closed system with CO2 gas pressure measured using a wireless pressure sensor.

Kinetics is the study of the rates of chemical reactions. When reactants are transformed into products in a chemical reaction, their amount decreases while the amount of products increases. How fast a chemical reaction goes is influenced by a number of factors: reactant concentration, temperature, particle size and the presence of catalysts. In this experiment, the decomposition of calcium carbonate in marble chips will be investigated using different concentrations of hydrochloric acid to better understand the kinetics and rates of this chemical reaction. The experiment begins with an introductory activity that measures CO2 gas production from CaCO3 decomposition in the presence of 6M HCl. Guided-inquiry activities are built around this model to investigate reaction rates at various concentrations of acid. Different student groups will work cooperatively to compare data. Initial rates and the rate law for the reaction will be graphically analyzed. Additional opportunities for inquiry will also be provided to investigate the effects of particle size, surface area or temperature on the reaction rate.

Pre-Lab Questions

1. The reaction rate is a function of the frequency of effective collisions between reactants. For a collision to be effective, the molecules must collide with sufficient energy and in the proper orientation so that products can form. Name one factor that affects the frequency or magnitude of molecular collisions and explain how it supports the collision theory.

2. Use the table of data below to determine the rate law for the reaction:

$$3F + 2H ® P + 2S$$

EXPERIMENT NUMBER	CONCENTRATION F (mol/L)	CONCENTRATION H (mol/L)	INITIAL REACTION RATE (mol/L s)
1	0.000345	0.000765	3.24×10^{-8}
2	0.000690	0.000765	3.24×10^{-8}
3	0.000537	0.00765	3.24×10^{-7}

3. Calculate the rate constant using correct units.

Materials and Equipment

Use the following materials to complete the initial investigation. For conducting an experiment of your own design, check with your teacher to see what materials and equipment are available.

- Data collection system
- Wireless pressure sensor
- One-hole stopper #6, connectors and pressure tubing
- Digital balance (0.01 g accuracy)
- Erlenmeyer flasks, 150-mL (3)
- Mortar and pestle
- Scoopula
- Beakers, 150-mL
- Ring stand with single clamp
- Graduated cylinders, 10- and 25-mL
- Weighing boats
- Distilled water and wash bottle
- Limestone samples, optional
- Calcium carbonate ($CaCO_3$), marble chips, 5 g
- Calcium carbonate ($CaCO_3$), granular, 5 g
- Blackboard chalk, optional
- Hydrochloric acid, 6.0 M
- Hydrochloric acid, 3.0 M
- Hydrochloric acid, 2.0 M
- Hydrochloric acid, 1.0 M
-

Safety

Follow these important safety precautions in addition to your regular classroom procedures:

- Wear safety goggles and gloves at all times. This lab uses a weak acid and a strong base.
- Hydrochloric acid is corrosive to skin and eyes and toxic by inhalation or skin absorption.
- Avoid contact of acid with skin and eyes and have handy a container of sodium bicarbonate to neutralize any acid spills.
- Do not use masses of calcium carbonate much greater than 0.5 g.
- Do not use concentrations of hydrochloric acid greater than 6M.
- Be mindful of inhaling calcium carbonate powder when handling.
- Wash hands thoroughly with soap and water before leaving laboratory.
- Review chemical handling and disposal instructions as directed by Material Safety Data Sheet.

Disposal

If your drain system is connected to a sanitary sewer system, the following instructions apply. Hydrochloric acid solutions may be rinsed down the drain with an excess of water. Excess marble chips and granular calcium carbonate may be disposed of in solid trash if contained in a sealed container such as a zippered plastic bag.

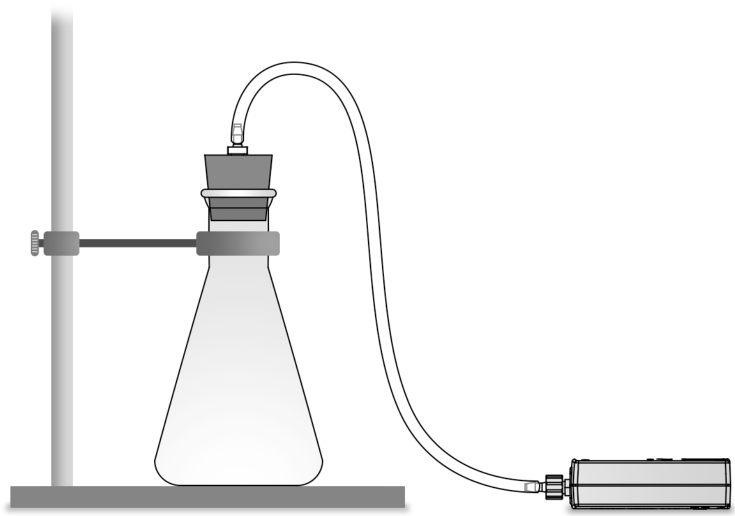
Initial Investigation

Reaction of calcium carbonate and hydrochloric acid

1. Start a new experiment on the data collection system from your Chromebook, computer or mobile device.

2. Connect the wireless pressure sensor to the data collection system. Open lab file *10 What Does Acid Rain Do?* or create a graph of Pressure (kPa) vs. Time (sec).

3. Set up a gas pressure apparatus as shown below.



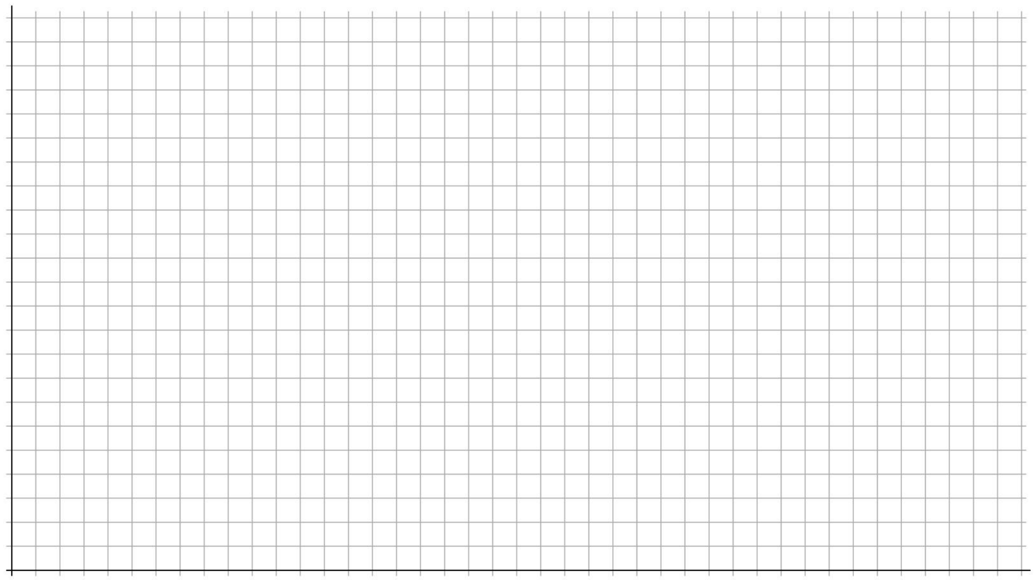
4. Measure and record the precise mass of approximately 0.5 g marble chips. Remove stopper and place chips in gas pressure apparatus.

5. Transfer 10.0 mL of 6 M hydrochloric acid and immediately replace the stopper and start data collection.

6. Continue data collection until marble chips are completely reacted (~2-3 minutes).

7. Graph the pressure (kPa) on the y-axis versus time (seconds) on the x-axis or attach data from lab file.

Reaction of Marble Chips with 6 M Hydrochloric Acid



8. Analyze the graph from the Introductory Investigation. Describe the shape of the curve and correlate it with the rate of carbon dioxide gas production and the concentration of hydrochloric acid versus time.

9. Determine the initial rate of reaction. The initial rate is calculated from the slope of the linear portion of the graph. Express the slope as kPa/sec/gram.

10. Calculate the number of moles of $CaCO_3$ reacted versus moles of HCl. Which reactant is limiting?

11. Calculate the theoretical number of moles of CO_2 produced in this reaction.

Advanced Investigation

Factors affecting reaction rate I: Concentration of acid

1. Start a new experiment on the data collection system from your Chromebook, computer or mobile device. Go to page 2 of the lab file or create a new graph of Pressure vs. Time (sec).

2. Repeat Steps 2-4 from the Initial Investigation.

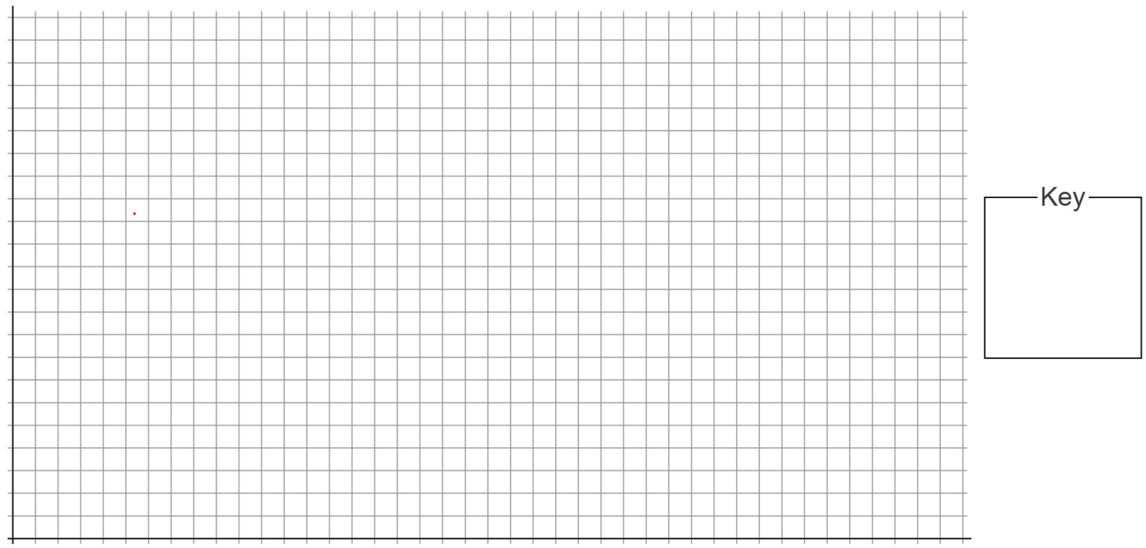
3. Transfer 10.0 mL of 3 M hydrochloric acid and immediately replace the stopper and start data collection.

4. Repeat Steps 6-11 from the Initial Investigation.

5. When completed, discard reaction mixture in the sink and wash with an excess of water. Rinse and wipe clean reaction flask.

6. Repeat procedure with 2 M and 1 M hydrochloric acid. Record data in the graph.

Effect of Acid Concentration on Rate of Reaction



7. Determine the initial rates of reaction for each acid concentration used in Table 1.

Table 1: Acid Concentration and Reaction Rates

Concentration of Acid (M)	
6	
3	
1	

8. What can you conclude from the initial rates of reaction for each acid concentration tested?

9. What can you conclude from the length of time for the reaction to reach completion?

Factors affecting reaction rate II: Surface area

1. Start a new experiment on the data collection system from your Chromebook, computer or mobile device. Go to page 3 of the lab file or create a new graph of Pressure vs. Time (sec).

2. Connect wireless pressure sensor to data collection system.

3. Measure and record the precise mass of approximately 0.5 g marble chips. Remove stopper and place chips in gas pressure chamber.

4. Measure and record the precise mass of approximately 0.5 g powdered calcium carbonate or crushed marble chips (using mortar and pestle). Set aside.

5. Which concentration of HCl do you plan to use for this investigation? Justify your answer.

6. Transfer 10.0 mL hydrochloric acid to marble chips in the gas pressure apparatus and immediately replace the stopper.

7. Begin data collection and graph results below and record calculated rates in Table 2.

8. Repeat the experiment using granular or powdered calcium carbonate.

   Note: Be mindful about keeping the flask stoppered. It is likely to pop during this reaction.

Effect of Surface Area on Rate of Reaction

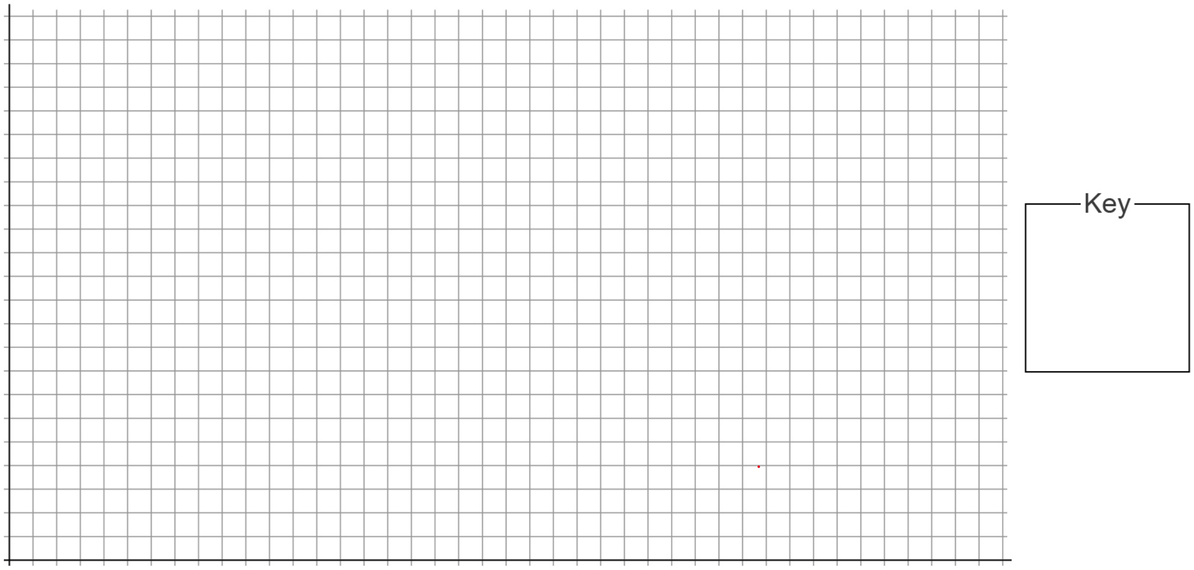


Table 2: Particle Size and Reaction Rate

Sample	Initial Rate (kPa sec^{-1} g^{-1})
Marble chips	
Powdered $CaCO_3$	

❓ 9. What can be concluded about the effect of particle size on initial reaction rates as determined in this investigation?

Extended Inquiry Investigation

1. Design an experiment to test other factors that may affect the rate of a reaction. These factors may include temperature, presence of a catalyst, etc. Prepare a detailed protocol to conduct this investigation and include predictions about possible outcomes of the experiment.

   Note: Handling warmed acid with care. Heating acid must be a task undertaken under strict instructor supervision.

2. Design an experiment to test alternative sources of $CaCO_3$: chalk, crushed seashells, construction limestone, etc. Calculate the initial rate per unit time and mass of material. How can you utilize this lab, its data and protocols to estimate what percentage of your sample is pure calcium carbonate?

3. If a classroom is not equipped with a pressure sensor, design an alternative method to measure the rate of decomposition of calcium carbonate. Measure volume of gas produced or the loss of mass by the reaction mixture.

Synthesis Questions

1. In developing a protocol to measure the rate of $CaCO_3$ decomposition by acid, a student is faced with three alternative methods of measuring the moles gas product generated by the reaction. These are measuring pressure, volume and mass. Which method(s) provides the highest accuracy for stoichiometry calculations? Explain your answer.

2. The rate law for the reaction of solid calcium carbonate with hydrochloric acid has the following form:

   $$\textbf{Rate} = \mathbf{k[HCl]^n}$$

   Explain why the concentration of calcium carbonate does not appear in the rate law.

AP® Chemistry Review Question

1. Given the following reaction: $M_2CO_3(s) + HCl(aq) \rightarrow MCl(aq) + CO_2(g) + H_2O(l)$ where M is a metal cation:

   2.002 g of anhydrous M_2CO_3 is reacted with excess HCl producing CO_2 as a product of the reaction. Using a mass difference method, the amount of CO_2 produced is determined to be 1.206 g.

   a. Write the balanced chemical equation for the reaction of the metal carbonate with hydrochloric acid.

   b. What is the mole ratio of reactant M_2CO_3 to product CO_2?

   c. How many moles of CO_2 were produced?

   d. Calculate the molar mass of the metal carbonate and identify the metal cation.