INVESTIGATION 10

How Long Will That Marble Statue Last?

■ CENTRAL CHALLENGE

Your task is to investigate how the speed of the chemical reaction between solid calcium carbonate and a solution of hydrochloric acid is affected by changing variables relating to the two reactants. You will implement the investigation by first constructing and then testing a hypothesis.

■ CONTEXT FOR THIS INVESTIGATION

Many historic buildings and monuments are made from limestone or marble. Limestone and marble are minerals that contain large amounts of calcium carbonate, $CaCO_3$. Since the industrial revolution, air pollutants, chiefly in the form of oxides of sulfur and nitrogen, have been absorbed into the atmosphere leading to the production of rainwater that has become significantly more acidic. This *acid rain* will react with the limestone, eroding it and causing much disfigurement and damage.

■ PRELAB GUIDING QUESTIONS/SIMULATIONS

The prelab guiding questions are designed to be completed as you think about the central challenge and the context of the investigation. They will help ensure that you are familiar with the vocabulary, and will help you prepare to create your own procedure and to perform the necessary calculations.

1. List the factors that you think may affect the speed at which calcium carbonate will react with acid. (The hydrochloric acid will be available to you in varying concentrations, and the calcium carbonate will be available in "chunks" of varying size. You will have access to a heat source.)
2. If a chemical reaction produces a gas, suggest a way of monitoring the production of that gas as the reaction proceeds.
3. Discuss how increasing the surface area of a solid might influence the rate of a chemical reaction.

EXPLANATION TO STRENGTHEN STUDENT UNDERSTANDING

The rate of a chemical reaction is explained by collision theory. Collision theory can be condensed into three large ideas that apply to the rate of all chemical reactions in which two or more molecules, atoms, or ions come together.

1. When substances are brought together in chemical reactions, the particles that make up those substances collide with one another. The collisions that occur between the particles are the first criteria for a reaction to take place. In potential reactions in which two or more molecules, atoms, or ions come together without those collisions, no actual reaction is possible.
2. The collisions that take place have to occur with a certain minimum energy. That minimum energy is called the activation energy. If the particles collide with insufficient energy — i.e., with an energy less than the activation energy — no reaction occurs and the particles simply bounce off one another without producing any products. Collisions that do not result in a reaction are called "unsuccessful."
3. The collisions must occur with the correct orientation — i.e., the particles must come together in a certain specific, physical way in which the atoms "line up" with one another, allowing a reaction to occur.

For a collision to be "successful"— i.e., for a collision to result in a chemical reaction in which reactants turn into products — the particles of the reactants must fulfill each of the three conditions of collision theory.

PREPARATION

Materials

Specific materials will depend upon the final experimental procedure determined by each student group; the likely materials for each experiment run by each group are listed below.

Marble or limestone chips (limestone/calcium carbonate), (approx. 2 large, 4 medium, or 8 small chips = 1.20–1.40 g)	Stoppers	Digital balance, with at least ±0.001g precision (as appropriate)
50.0 mL of hydrochloric acid (HCl) of varying concentration, for example , 6.0 *M*, 5.0 *M*, 4.0 *M*, 3.0 *M*, 2.0 *M*	Syringes	Glass delivery tubes and rubber tubing

Water (preferably deionized or distilled, but this isn't crucial) for dilution of a concentrated stock solution of HCl (alternatively prediluted HCl)	As an alternative to gas syringes, equipment suitable for the collection of gas over water (i.e., a eudiometer or gas jar)	Stopwatches, or students can use an online app for timing purposes
125 mL Erlenmeyer flasks	Labquest and probeware (gas pressure probes) as an alternative way of collecting data	

Safety and Disposal

Safety: 6.0 *M* hydrochloric acid is hazardous and needs to be handled with care. Goggles and protective aprons are required. You should not generate gases in closed containers since there is a risk of explosion as pressure builds. When diluting acids, acid should be added to water, not water to acid.

Disposal: Any excess solid calcium carbonate should be removed from solution and disposed of in the trash. All solutions can be diluted and washed down the sink with plenty of water.

■ PRACTICE WITH INSTRUMENTATION AND PROCEDURE

Your teacher will guide you through the process of identifying variables that may affect the rate of reaction of hydrochloric acid with calcium carbonate, which is meant to simulate the effects of acid rain on marble statues. Upon identification of variables, you will need to write at least two research questions pertaining to this reaction using the following format:

To what extent does A affect B?

(where A is the independent variable and B is the dependant variable)

Procedure

Your teacher may ask you to mix varying amounts of hydrochloric acid solutions and marble chips so you can get a sense of the relative speed of the reactions, and perhaps get some ideas about what you might be able to measure and observe. It might be useful to have the reaction vessel placed on an electronic balance as you make these initial observations.

■ INVESTIGATION

Once students develop one to two research questions (from the Practice section) to gather data for, students should design experiments for each of the questions to collect data that will allow them to draw conclusions about the effect of those

variables on the rate of this reaction. The chemical reaction that will be studied is the reaction of hydrochloric acid with calcium carbonate, summarized by the equation below.

$$2HCl(aq) + CaCO_3(s) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$$

Procedure

1. Design an experimental procedure and data-collection strategy to monitor some aspect of the reaction (according to the two research questions you developed in the Practice section) in order to find a rate of reaction.
2. Formulate a hypothesis for how the independent variable will affect the dependant variable in each of your research questions.
3. Show your teacher your proposed procedure before attempting your experiment. Once your initial experimental design has been carried out and data collected, consider improvements to your procedure and perform the investigation once more, but show your procedure with changes to your teacher before trying it.

Data Collection and Computation

1. List the measurements that you took during the experiments.
2. Consider how the data or measurements should be recorded and presented to illustrate your findings and then place such data representation in a central location in the lab for the purpose of engaging in whole-group discussion about the variables that affect the rate of reaction between hydrochloric acid and calcium carbonate.
3. Use the data you have collected to comment on your original hypothesis.

Argumentation and Documentation

During whole-group discussion, using the data the students displayed in a central location of the lab, listen to each lab group present their findings and comment on whether or not their data supported or refuted their hypotheses.

Be prepared to defend the changes you made to your experimental design to ensure consistency in the data collection.

Be prepared to defend why you chose a particular treatment of the data to illustrate your findings to the class and to support or refute your hypotheses.

Your teacher will give you additional information about acid rain and marble statues. Be prepared to generalize the findings of your experiment to estimate how long it would take marble statues to disintegrate under specific conditions.

POSTLAB ASSESSMENT

Consider the following question.

An experiment was carried out in order to investigate the rate of reaction between magnesium and dilute hydrochloric acid. 0.07 g of magnesium ribbon was reacted with excess dilute acid. The volume of gas produced every 5.00 seconds was recorded.

Seconds	Volume of Gas Collected (mL)
0	0
5	18
10	34
15	47
20	57
25	63
30	67
35	69
40	70
45	70

a. Plot a graph of these results.

b. When is the reaction fastest? How can you use the graph to determine when the reaction is the fastest?

c. How long does it take for the 0.07 g of magnesium to react completely with the dilute hydrochloric acid?

d. Sketch another curve on to your graph that might have been obtained if 0.07 g of magnesium powder had been used instead of magnesium ribbon.

e. Suggest two other factors that would alter the rate of this reaction.

f. Write a chemical reaction for this process.

SUPPLEMENTAL RESOURCES

Links

Blauch, David N. "The Bromate-Bromide Reaction." Davidson College. Accessed July 30, 2012.
http://www.chm.davidson.edu/vce/kinetics/BromateBromideReaction.html

Greenbowe, Tom. "Chemical Kinetics." Iowa State. Accessed July 30, 2012.
http://group.chem.iastate.edu/Greenbowe/sections/projectfolder/flashfiles/kinetics2/kinetics.html

Greenbowe, Tom. "Kinetics 2: Reaction Rate 01." Iowa State. Accessed July 30, 2012. *http://group.chem.iastate.edu/Greenbowe/sections/projectfolder/flashfiles/kinetics2/rxnRate01.html*

"Investigating the Rate of a Reaction." Creative Chemistry. Accessed July 30, 2012. *http://www.creative-chemistry.org.uk/gcse/documents/Sc1/rates.pdf*

"Module 3 Revision Notes — Rates of Reaction and Collision Theory." Science Pages. Accessed July 30, 2012. *http://www.richardanderson.me.uk/keystage4/GCSEChemistry/m3ratesofreaction.php*

"Reactions and Rates." University of Colorado at Boulder, PhET Interactive Simulations. Accessed July 30, 2012. *http://phet.colorado.edu/en/simulation/reactions-and-rates*

References

Copper, Christine L., and Edward Koubeck. "An Experiment to Demonstrate How a Catalyst Affects the Rate of a Reaction." *Journal of Chemical Education* 76, no. 12 (1999): 1714-15. Accessed July 30, 2012. *http://pubs.acs.org/doi/abs/10.1021/ed076p1714?prevSearch=Rates%2Bof%2BReaction&searchHistoryKey=*

Eliason, Robert, and Terence McMahon. "Temperature Effect on Reaction Rates." *Journal of Chemical Education* 58, no. 4 (1981). Accessed July 30, 2012. *http://pubs.acs.org/doi/abs/10.1021/ed058p354.1?prevSearch=Rates%2Bof%2BReaction&searchHistoryKey=*

Evenson, Andy. "Putting Reaction Rates and Collision Theory in the Hands of Your Students." *Journal of Chemical Education* 79, no. 7 (2002): 822–23. Accessed July 30, 2012. *http://pubs.acs.org/doi/abs/10.1021/ed079p822?prevSearch=Rates%2Bof%2BReaction&searchHistoryKey=*

Mickey, Charles D. "Chemical Kinetics: Reaction Rates." *Journal of Chemical Education* 57, no. 9 (1980): 659. Accessed July 30, 2012. *http://pubs.acs.org/doi/abs/10.1021/ed057p659?prevSearch=Rates%2Bof%2BReaction&searchHistoryKey=*