9. FACTORS THAT AFFECT REACTION RATE

Initial Question

In some cases we want reactions to proceed quickly, for example, for air bag deployment or certain processes used in manufacturing. In other cases, we want reactions to proceed slowly, such as the corrosion of car parts or aging. Scientists have discovered many factors, or variables, that can be manipulated to change the rate of a reaction. In this investigation, you explore one factor that may alter the rate of a reaction and share what you've found with your classmates.

How can we speed up or slow down a chemical reaction?

Materials and Equipment

Model 1 and Model 2

- Data collection system
- Temperature sensor
- Pressure sensor
- Quick-release connector
- Tubing, 1- to 2-cm
- Tubing connectors
- Two-hole stopper to fit flask
- Erlenmeyer flask, 125-mL
- Graduated cylinder, 50-mL
- Syringe, 60-mL
- Mortar and pestle

Model 1

- Calcium carbonate ($CaCO_3$), solid, 0.2 g
- 3.0 M Hydrochloric acid (HCl), 1 mL
- Distilled water, 50 mL

Model 2

- Equipment and amounts depend on the variable:
- Beaker for ice bath
- Beaker (4), 50-mL
- Graduated cylinder, 10-mL
- Magnetic stir bar
- Stir plate
- Hot plate
- Calcium carbonate ($CaCO_3$)
- 3.0 M Hydrochloric acid (HCl)
- Ice
- Distilled water

Safety

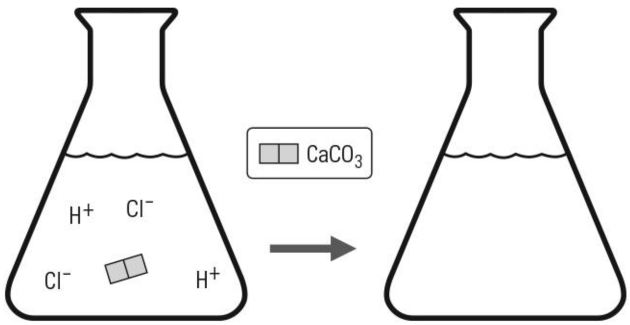
Add these important safety precautions to your normal laboratory procedures:

- Treat all unknowns as a hazardous, toxic, and harmful material.
- All unknowns will need to be disposed of in the proper waste container.
- Hydrochloric acid is highly corrosive; it will damage human tissue and clothing. If you get hydrochloric acid on your skin, flush the area with large amounts of water.

Getting Your Brain in Gear

1. In this lab, you will be mixing calcium carbonate solid with a solution of hydrochloric acid. Write a balanced equation for the reaction that will occur. Include phase notation.

2. Draw a particle-level representation diagram of the balanced equation.



3. Gas pressure is defined as a collision of gas particles. Do the reactants or the products have more gas pressure?

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4. What particles are colliding to make the reaction progress?

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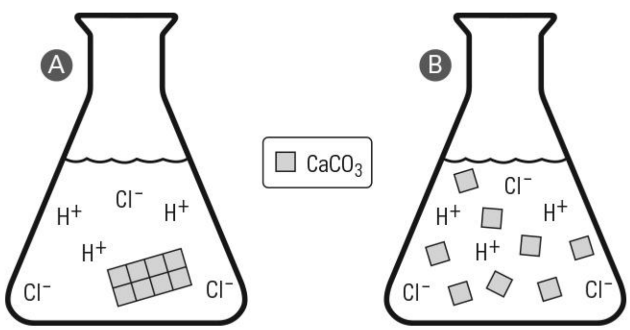
5. Which of the following would have more collisions? Justify your answer.



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MODEL 1

Building Model 1 – The Change in Pressure during a Reaction

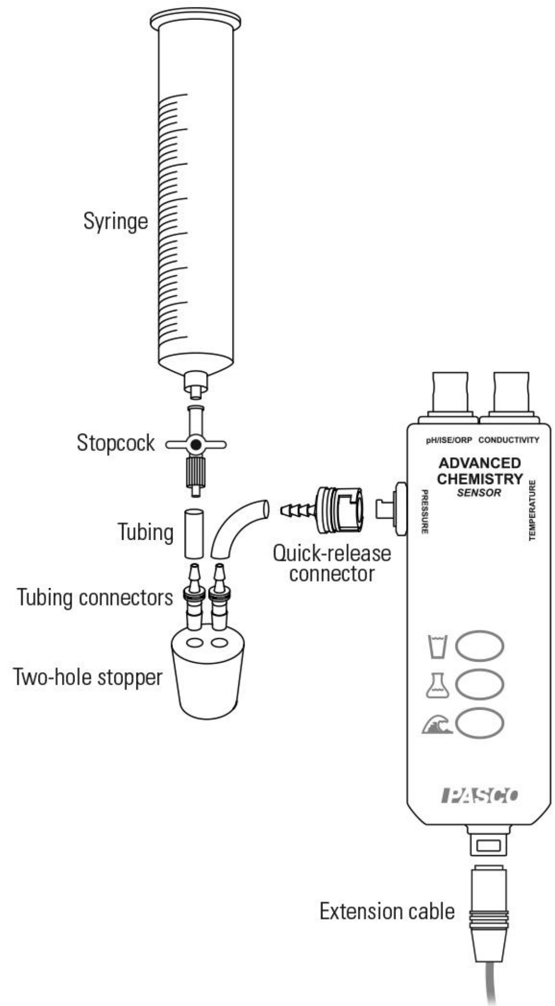
1. Prepare the reaction apparatus by completing the following steps.

   a. Connect the pressure sensor to the two-hole stopper: place the barbed connector of the pressure sensor tightly into the rubber stopper and connect it to the pressure port of the sensor with a piece of tubing.

   b. Connect the syringe to the stopcock connected to the other hole of the two-hole stopper. Close the stopcock.

   c. Place the two-hole stopper tightly into the 125-mL Erlenmeyer flask.

   d. Check for leaks in the system by opening the stopcock, pulling up on the syringe, and holding for 10 seconds. Then release the plunger of the syringe. It should return to its original position if there are no leaks.



2. Connect the pressure sensor and temperature sensor to the data collection system and start a new experiment. Display the pressure on the *y*-axis of a graph and time on the *x*-axis

3. Break off a small piece of white chalk (which is primarily calcium carbonate) and use the mortar and pestle to crush it into a fine powder. Measure approximately 0.2 g of the chalk powder. Record the mass in the Model 1 Data Table. Transfer the calcium carbonate sample to the 125-mL Erlenmeyer flask quantitatively.

4. Add 50 mL of distilled water to the Erlenmeyer flask, reinsert the stopper into the flask, and check again for leaks.

5. Close the stopcock and remove the syringe. Remove the plunger and place 1.0 mL of 3.0 M hydrochloric acid (HCl) into the syringe, keeping the syringe horizontal so the solution doesn't spill out. Replace the plunger and return the syringe to the reaction apparatus by twisting it gently back onto the stopcock.

   NOTE: Because of the short tubing, the syringe sits vertically above the flask.

6. Begin data collection. Record the pressure in the Erlenmeyer flask for 10 seconds.

7. At the ten second mark open the stopcock. If the contents of the syringe do not completely empty into the reaction flask, apply gentle pressure to the plunger. Once this transfer has occurred, quickly close the stopcock once again.

8. Gently swirl the flask while collecting data for at least 5 minutes.

9. Record the room temperature in the Model 1 Data Table after converting it to Kelvin.

❓ 10. Which of the following gases are in the flask in quantities greater than or equal to at least ~1% before the HCl is introduced?

Nitrogen	Oxygen	Argon	Chlorine
Carbon dioxide	Water vapor	Hydrogen	Carbon monoxide

❓ 11. Which of the gases are in the flask after the reaction has occurred?

❓ 12. Explain why the pressure is increasing in the flask during the reaction. Support your answer with concepts from the kinetic molecular theory.

13. Use the time versus pressure graph to determine the pressure in the flask at 10 seconds and at 3 minutes. Record these values in the Model 1 Data Table.

Model 1 – The Change in Pressure during a Reaction

Table 1: Model 1 Data Table—Reaction measurements and results

Parameter	Value
Volume of reaction vessel (mL)	
Mass of chalk ($CaCO_3$) (g)	
Volume of 3.0 M HCl (mL)	
Pressure of gas at 10 sec (kPa)	
Pressure of gas at 3 minutes (kPa)	
Room temperature	

Analyzing Model 1 – The Change in Pressure during a Reaction

14. Calculate the partial pressure of carbon dioxide in the flask at 3 minutes. Assume there was no carbon dioxide in the flask before the reaction.

15. Calculate the number of moles of carbon dioxide in the flask at 3 minutes using the Ideal Gas Law.

    NOTE: Some of the flask volume was occupied by liquid and solid. Assume the volume of the gas is the same as the Erlenmeyer flask 125 mL, or 0.125 L.

16. Calculate the rate of reaction with respect to the production of carbon dioxide for the trial in Model 1.

17. Compare your rate to that of other groups. Is there appreciable difference in the rates? What should be done if a lab group has data that is very different from the rest of the class?

MODEL 2

Building Model 2 – Factors That Affect Rate

1. List at least five variables that could be tested with the same reaction system as Model 1 to determine if they affect the rate of the reaction. Be prepared to share your list with the class.

2. Your instructor will assign a variable for you to test using the reaction system in Model 1. Develop a procedure for a controlled experiment to test that variable. You will need at least four trials. Record your procedure below and design the Model 2 Data Table.

   List the variable(s) in each category for the lab procedure you develop:

   Independent: __________

   Dependent: __________

   Controlled: __________

Procedure:

❷ 3. Calculate the rate of reaction for each trial. Use the calculations you performed in Model 1 as an example.

❷ 4. In the Model 2 data section, sketch or attach a copy of your graph that shows the relationship between the rate of reaction and your independent variable. Be prepared to share your findings with the class.

Model 2 – Factors That Affect Rate

Model 2 Data Table:

Analyzing Model 2 – Factors That Affect Rate

5. As your classmates summarize their findings, fill in the following relationships. The first blank is for the independent variable. The second blank should be "increased," "decreased," or "stayed the same."

Observations:

A: As ______________________ increased, the rate of reaction ______________

B: As ______________________ increased, the rate of reaction ______________

C: As ______________________ increased, the rate of reaction ______________

D: As ______________________ increased, the rate of reaction ______________

E: As ______________________ increased, the rate of reaction ______________

F: As ______________________ increased, the rate of reaction ______________

G: As ______________________ increased, the rate of reaction ______________

Connecting to Theory

A reaction mechanism is a series of chemical reactions that illustrate the actual pathway reactants undergo to become products. This usually involves several steps. When the steps are combined, reactants that appear on opposite sides of the arrows cancel, resulting in the net ionic equation. For example,

1.	$CaCO_3(s) + H^+ + Cl^-$	$\rightleftharpoons$	$Ca^{2+} + HCO_3^- + Cl^-$
2.	$HCO_3^- + H^+ + Cl^-$	$\rightleftharpoons$	$CO_2(g) + H_2O + Cl^-$
Net ionic equation:	$CaCO_3(s) + 2H^+$	$\rightleftharpoons$	$CO_2(g) + H_2O + Ca^{2+}$

One of the steps usually takes significantly more time to complete than the others. The slower step is known as the *rate determining* step. It is so slow compared to the others that we consider it to take all of the reaction time and the other steps to take no time at all.

The order of the reaction is determined by the slow step. If step 1 in this example is the rate determining step, then the reaction is first order with respect to both $CaCO_3$ and HCl, represented as $H^+ + Cl^-$, because one $CaCO_3$ molecule is reacting with one HCl molecule. However if step 2 is the rate determining step, the reaction is zero order with respect to $CaCO_3$ because it does not appear in that step and first order with respect to HCl because one HCl molecule is present.

This reaction is convenient for laboratory use but difficult to use when writing a rate law because $CaCO_3$ is a solid. The rate law is in the form: Rate = $k[a]^m[b]^n$, where "k" is the rate constant, "a" and "b" are the reacting species and "m" and "n" are the respective reaction orders. The brackets refer to the concentration of the reactant.

Since $CaCO_3$ is a solid, it cannot have a concentration. The value for $CaCO_3$ does not appear in the rate law. It becomes incorporated into the rate constant.

Applying Your Knowledge – Analyzing Model 2

The reactants in a reaction mechanism must collide before they can become products. Chemists use the Collision Theory to explain observations related to reaction rate and to predict how certain variables might alter the rate of a reaction. The Collision Theory states:

- For a reaction to occur, reactant particles must collide.
- For a reaction to occur, the particles in the collision must have sufficient energy to overcome the activation energy for the reaction.
- For a reaction to occur, the particles in the collision must be oriented correctly.

1. If a collision between reactant particles is required for a reaction, what should happen to the rate of reaction if the number of collisions per second is increased?

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2. Which of the variables tested in this lab would affect the number of collisions per second between reactant particles?

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3. Refer to Model 2. Do the observations made in the lab support or refute your answer to the previous question? List specific examples and discuss any discrepancies.

4. If the particles in a reaction have sufficient energy for a collision to be successful, what should happen to the rate of reaction if the average kinetic energy of the system is increased?

5. Which of the variables tested in this lab would affect the average kinetic energy of the system?

6. Do the observations made in Model 2 support or refute your answer to the previous question? List specific examples and discuss any discrepancies.

7. Were there any variables tested in Model 2 that affected the rate and were not discussed in previous questions? If yes, propose how the variable tested relates to the collision theory and therefore affects the rate of reaction.