Name **Period** **Date**

22. Rates of Reaction

Driving Questions

Many products, such as medicines and food, have expiration dates. Refrigeration is known to lengthen the time before meat, eggs, dairy, and produce spoil; blocks of cheese remain edible longer than grated cheese. The shelf-lives of these products have been determined by chemists. What factors influence the speed at which chemical reactions take place?

Background

Kinetics is the branch of chemistry that studies the rates of chemical reactions. Some reactions, such as lighting a match, occur very quickly and thus have large values for their reaction rates. Other reactions, such as the formation of rust, occur more slowly and thus have smaller rates of reaction.

Collision theory explains that reacting particles must collide with each other for a reaction to occur and that these collisions must occur with enough energy to react. Increasing the frequency of collisions directly increases the speed at which a reaction takes place; the more often reacting particles collide, the greater the chance of them reacting. The rate of reaction can be directly affected by changing the frequency of the collisions. This can be accomplished by changing the temperature (warmer particles move faster), the concentration of the reactants (greater concentrations have more particles in an area), or the amount of exposed area on the surface of the reacting particles (larger surface areas provide more space for reactants to contact each other).

In this experiment, the various factors that affect the reaction rate of magnesium metal with hydrochloric acid will be investigated. The chemical equation for this reaction is given below.

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

Materials and Equipment

For each student or group:

- Data collection system
- Absolute pressure sensor
- Sensor extension cable
- Test tube (3), 20-mm x 150-mm
- Test tube rack
- One-hole stopper to fit the test tubes
- Quick-release connector
- Tubing connector
- Tubing, 1- to 2-cm
- Glycerin
- 4.0 M Hydrochloric acid (HCl), 5 mL
- 2.0 M Hydrochloric acid (HCl), 5 mL
- 1.0 M Hydrochloric acid (HCl), 20 mL
- 0.1 M Hydrochloric acid (HCl), 5 mL
- Warm and cold water baths[4] (one per class)
- Magnesium ribbon (18), 1-cm pieces
- Magnesium powder, 0.05 g

Safety

Add these important safety precautions to your normal laboratory procedures:

- Do not hold the stopper in the tube beyond a pressure of 125 kPa (1.2 atm).
- Do not point the test tube towards yourself or anyone else.
- Hydrochloric acid is a corrosive irritant. Avoid contact with the skin and eyes.
- Be sure that all acids and bases are neutralized before being disposed of down the drain.

Sequencing Challenge

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

◯	◯	◯	◯	◯
Begin recording data (before the reactants are mixed).	Add hydrochloric acid solution to a test tube.	Carefully release the stopper when the pressure reaches 125 kPa (1.2 atm). Stop recording data.	Add magnesium metal to test tube containing HCl and quickly seal the test tube using the stopper.	Analyze the results to determine the various factors affecting reaction rates.

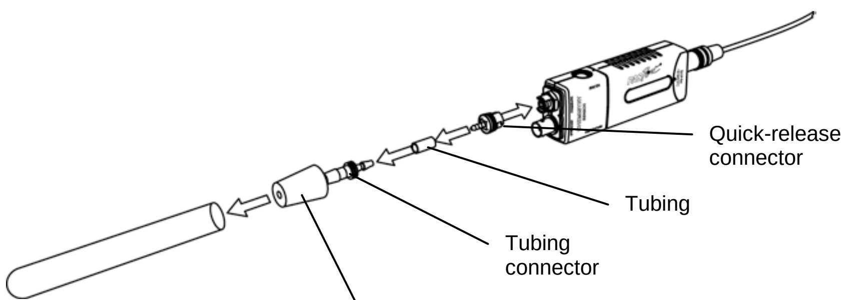
Procedure

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

Note: When you see the symbol "�" with a superscripted number following a step, refer to the numbered Tech Tips listed in the Tech Tips appendix that corresponds to your PASCO data collection system. There you will find detailed technical instructions for performing that step. Your teacher will provide you with a copy of the instructions for these operations.

Set Up

1. ☐ Complete the following steps to attach the one-hole stopper to the absolute pressure sensor:
   a. Insert the thicker end of the tubing connector into the hole in the rubber stopper. If this is difficult, add a drop of glycerin.
   b. Connect the 1- to 2-cm piece of tubing to the other, thinner end of the tubing connector.
   c. Insert the barbed end of a quick-release connector into the open end of the 1- to 2-cm piece of tubing. If this is difficult, add a drop of glycerin.
   d. Insert the quick-release connector to the port of the absolute pressure sensor and then turn the connector clockwise until the fitting “clicks” onto the sensor (about one-eighth turn).



2. ☐ Start a new experiment on the data collection system. �(1.2)

3. ☐ Use a sensor extension cable to connect the absolute pressure sensor to the data collection system. �(2.1)

4. ☐ Display Absolute Pressure (kPa) versus Time (s) on a graph. �(7.1.1)

5. ☐ When you mix magnesium ribbon and hydrochloric acid together inside a closed test tube what do you expect to happen to the pressure? Why?

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Part 1 – Establish a baseline reaction rate

Collect Data

6. ☐ Add 5 mL of 1.0 M HCl into a test tube labeled "baseline".

7. ☐ Start recording data. �(6.2)

8. ☐ Add three 1-cm pieces (0.05 g) of magnesium ribbon to the test tube and quickly place the stopper attached to the absolute pressure sensor in the test tube.

CAUTION: Apply gentle pressure to keep the stopper in, but do *not* hold the stopper in the tube beyond a pressure of 125 kPa.

CAUTION: Do not point the test tube towards yourself or anyone else.

Note: You may have to adjust the scale of the graph to observe any changes taking place. �(7.1.2)

9. ☐ Carefully remove the stopper when the pressure reaches 125 kPa and then stop recording data. �(6.2)

10. ☐ Why is it important not to let the pressure in the test tube exceed 125 kPa?

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11. ☐ Rename the data run "baseline". �(8.2)

12. ☐ Why is it important to clearly label each run?

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13. ☐ Is the magnesium dissolving in or reacting with the HCl? Explain your reasoning.

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14. ☐ Dispose of the contents of the test tube according to the teacher's instructions and then rinse the test tube with water so it can be re-used in the next part of the lab.

Analyze Data

15. ☐ Find the slope (reaction rate) of the initial linear portion of the data run by following the steps below.

 a. Apply a linear fit to the first 10 to 20 seconds of the data run after the magnesium was added. �(9.5)

 b. Determine the slope of the linear fit line. �(9.6)

 c. Record the slope below.

 Baseline slope = ______________________

16. ☐ What does the slope of this line represent?

Part 2 – The effect of temperature on the rate of reaction

Set Up

17. ☐ Add 5 mL of 1.0 M HCl into each of two different test tubes (one labeled "hot" and the other labeled "cold").

18. ☐ Place the test tube labeled "hot" into a warm water bath (40 to 50 °C) and the test tube labeled "cold" into an ice-water bath (0 to 5 °C). Leave the test tubes in the water baths for 5 to 10 minutes to allow the HCl solutions to attain the appropriate temperatures.

19. ☐ Predict the effect of temperature on the rate of reaction. Explain your prediction using your knowledge of what is happening at the molecular level.

20. ☐ What is the independent variable in this part of the experiment?

Collect Data

21. ☐ Complete the following steps to measure the change in pressure as magnesium reacts with the “hot” HCl.

    a. Remove the test tube from the warm water bath.

    b. Start recording data. �(6.2)

    c. Add three 1-cm pieces (0.05 g) of magnesium ribbon to the test tube and quickly place the stopper attached to the absolute pressure sensor in the test tube.

    Note: You may have to adjust the scale of the graph to observe any changes taking place. �(7.1.2)

    d. Stop recording data when the pressure reaches 125 kPa. �(6.2)

    e. Rename this data run “hot”. �(8.2)

22. ☐ Complete the following steps to measure the change in pressure as magnesium reacts with the “cold” HCl.

    a. Remove the test tube from the cold water bath.

    b. Start recording data. �(6.2)

    c. Add three 1-cm pieces (0.05 g) of magnesium ribbon to the test tube and quickly place the stopper attached to the absolute pressure sensor in the test tube.

    Note: You may have to adjust the scale of the graph to observe any changes taking place. �(7.1.2)

    d. Stop recording data when the pressure reaches 125 kPa. �(6.2)

    e. Rename this data run “cold”. �(8.2)

23. ☐ Why are you testing “hot” and “cold” HCl but not HCl at room temperature?

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24. ☐ Dispose of the contents of the test tubes according to the teacher’s instructions and then rinse the test tubes with water so they can be re-used in the next part of the lab.

Analyze Data

25. ☐ Find the slope (reaction rate) of the initial linear portion of the data run for both the "hot" and "cold" HCl reacting with magnesium.

a. Display the run of data you want to analyze. �(7.1.7)

b. Apply a linear fit to the first 10 to 20 seconds of the data run after the magnesium was added. �(9.5)

c. Determine the slope of the linear fit line. �(9.6)

d. Record the slopes in Table 1 below.

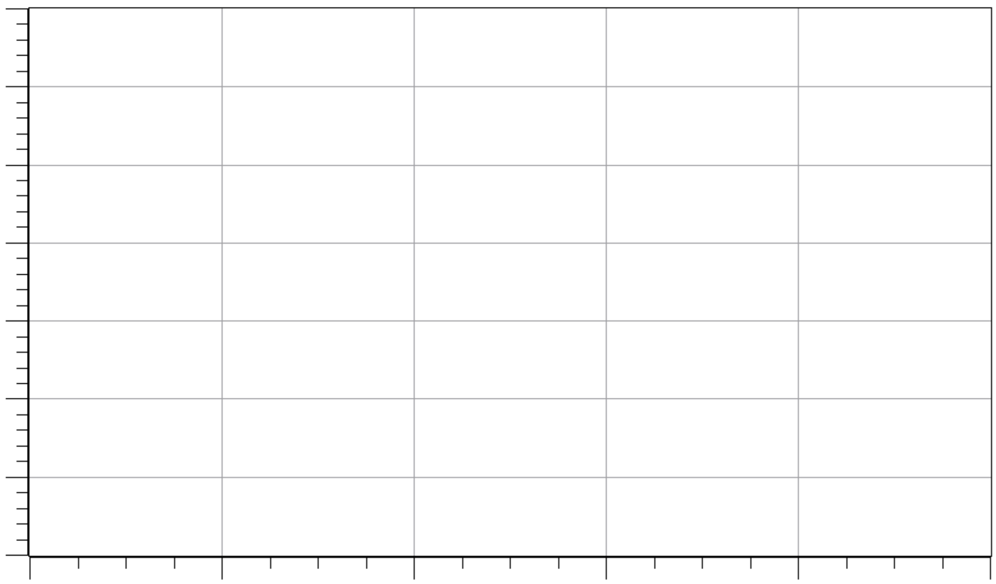
Table 1: Slopes of data runs for Mg reacting with HCl at different temperatures

Reaction Conditions	**Slope (kPa/s)**
Room temperature 1.0 M HCl + Mg ribbon (baseline reaction from Part 1 above)	
"Hot" 1.0 M HCl + Mg ribbon	
"Cold" 1.0 M HCl + Mg ribbon	

26. ☐ Create a graph with all three runs of data displayed on your data collection system. �(7.1.7)

Note: Not all data collection systems will display all three runs of data on one set of axes.

27. ☐ Sketch or print a copy of the Absolute Pressure (kPa) versus Time (s) graph displaying the data collected when 1.0 M HCl and magnesium ribbon were reacted at three different temperatures (hot, cold, and room temperature). Label each data run as well as the overall graph, the x-axis, the y-axis, and include units on the axes. �[(11.2)]



Part 3 – The effect of surface area on the rate of reaction

Set Up

28. ☐ Which has a greater surface area, powdered magnesium or 1-cm pieces of magnesium ribbon?

____

29. ☐ Predict the effect of surface area on the rate of reaction. Explain your prediction using what you know is happening at the molecular level.

____

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30. ☐ Add 5.0 mL of 1.0 M HCl into a test tube labeled “Mg powder”.

Collect Data

31. ☐ Start recording data. �(6.2)

32. ☐ Add ~0.05 g of magnesium powder to the HCl and quickly place the stopper attached to the absolute pressure senor in the test tube.

Note: You may have to adjust the scale of the graph to observe any changes taking place. �(7.1.2)

33. ☐ Stop recording data when the pressure reaches 125 kPa. �(6.2)

34. ☐ Rename this data run "Mg powder". �(8.2)

35. ☐ Dispose of the contents of the test tube according to the teacher's instructions and then rinse the test tube with water so it can be re-used in the next part of the lab.

Data Analysis

36. ☐ Find the slope (reaction rate) of the initial linear portion of the data run for the reaction between 1.0 M HCl and powdered magnesium.

    a. Display the run of data you want to analyze. �(7.1.7)

    b. Apply a linear fit to the first 10 to 20 seconds of the data run after the magnesium was added. �(9.5)

    c. Determine the slope of the linear fit line. �(9.6)

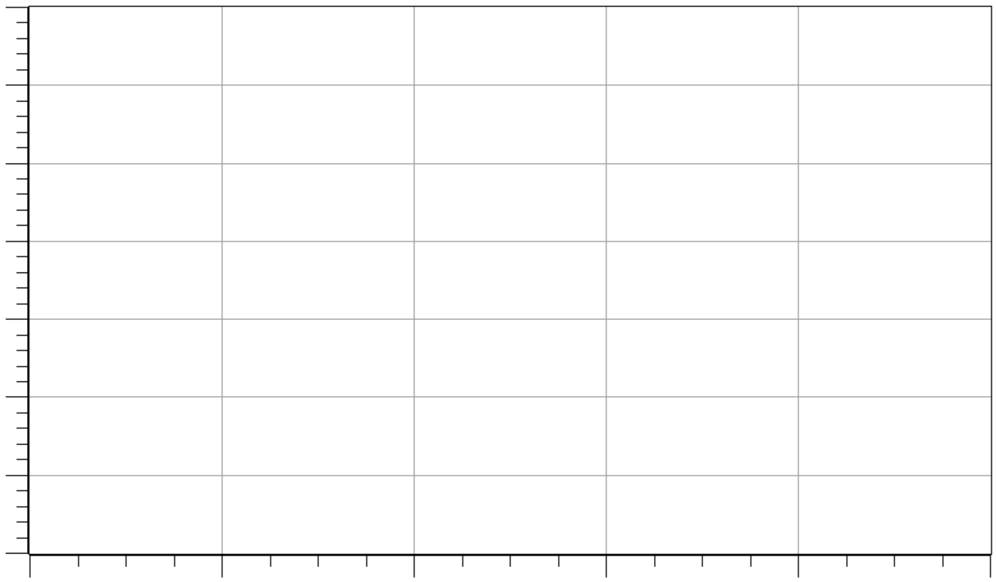
    d. Record the slope in Table 2 below.

Table 2: Slopes of data runs for Mg ribbon and Mg powder reacting with HCl

Reaction Conditions	Slope (kPa/s)
1.0 M HCl + Mg ribbon (baseline reaction from Part 1 above)	
1.0 M HCl + Mg powder	

37. ☐ Create a graph with both runs of data (Mg ribbon and Mg powder) displayed on your data collection system. �(7.1.7)

38. ☐ Sketch or print a copy of the Absolute Pressure (kPa) versus Time (s) graph displaying the reaction between 1.0 M HCl and magnesium powder and the reaction between 1.0 M HCl and magnesium ribbon. Label each data run as well as the overall graph, the x-axis, the y-axis, and include units on the axes. �(11.2)



Part 4 – The effect of concentration on the rate of reaction

Set Up

39. ☐ How are 1 M and 2 M HCl solutions different? Use the term "concentration" in your explanation.

40. ☐ Predict the effect of concentration on the rate of reaction. Explain your prediction using what you know is happening at the molecular level during a chemical reaction.

____

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____

41. ☐ Measure 5 mL of 0.1 M, 2.0 M, and 4.0 M HCl into three different test tubes. Label each test tube with the corresponding concentration.

Collect Data

42. ☐ Complete the following steps to measure the change in pressure as magnesium reacts with the 0.1 M HCl.

a. Start recording data. �(6.2)

b. Add three 1-cm pieces (0.05 g) of magnesium ribbon into the test tube and quickly place the stopper attached to the absolute pressure sensor in the test tube.

Note: You may have to adjust the scale of the graph to observe any changes taking place. �(7.1.2)

c. Stop recording data when the pressure reaches 125 kPa. �(6.2)

d. Rename this data run "0.1 M HCl". �(8.2)

43. ☐ Complete the following steps to measure the change in pressure as magnesium reacts with the 2.0 M HCl.

a. Start recording data. �(6.2)

b. Add three 1-cm pieces (0.05 g) of magnesium ribbon into the test tube and quickly place the stopper attached to the absolute pressure sensor in the test tube.

Note: You may have to adjust the scale of the graph to observe any changes taking place. �(7.1.2)

c. Stop recording data when the pressure reaches 125 kPa. �(6.2)

d. Rename this data run "2.0 M HCl". �(8.2)

44. □ Complete the following steps to measure the change in pressure as magnesium reacts with the 4.0 M HCl.

a. Start recording data. �(6.2)

b. Add three 1-cm pieces (0.05 g) of magnesium ribbon into the test tube and quickly place the stopper attached to the absolute pressure sensor in the test tube.

Note: You may have to adjust the scale of the graph to observe any changes taking place. �(7.1.2)

c. Stop recording data when the pressure reaches 125 kPa. �(6.2)

d. Rename this data run "4.0 M HCl". �(8.2)

45. □ Save the data file and clean up according to the teacher's instructions. �(11.1)

Analyze Data

46. □ Find the slope of the initial linear portion of the data run for the reactions between magnesium ribbon and 0.1 M, 2.0 M, and 4.0 M HCl.

a. Display the run of data you want to analyze. �(7.1.7)

b. Apply a linear fit to the first 10 to 20 seconds of the data run after the magnesium was added. �(9.5)

c. Determine the slope of the linear fit line. �(9.6)

d. Record the slopes in Table 3 below.

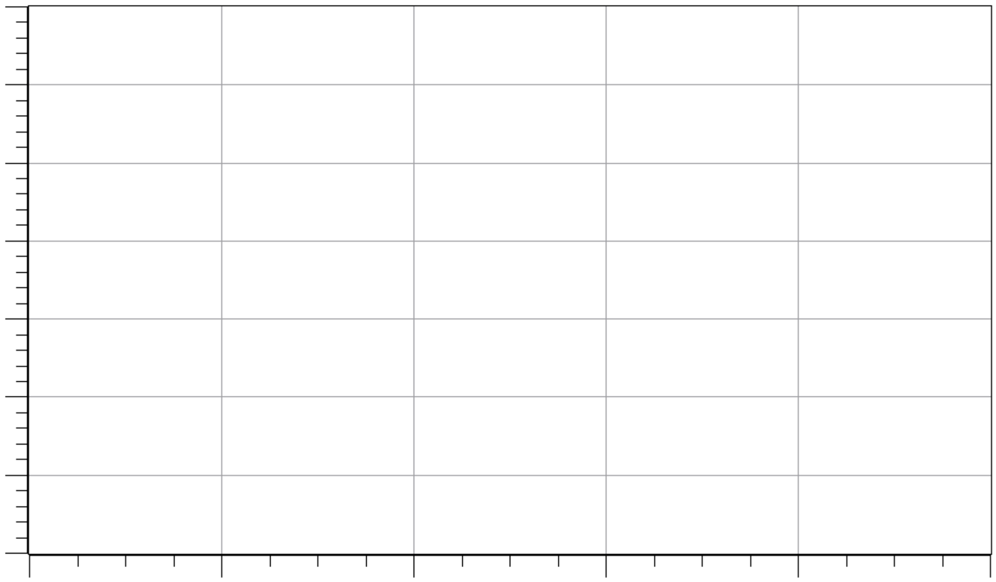
Table 3: Slopes of data runs for Mg reacting with different concentrations of HCl

Reaction Conditions	**Slope (kPa/s)**
0.1 M HCl + Mg ribbon	
1.0 M HCl + Mg ribbon (baseline reaction from Part 1 above)	
2.0 M HCl + Mg ribbon	
4.0 M HCl + Mg ribbon	

47. □ Create a graph with all four runs of data displayed on your data collection system. �(7.1.7)

Note: Not all data collection systems will display all four runs of data on one set of axes.

48. ☐ Sketch or print a copy of the Absolute Pressure (kPa) versus Time (s) graph displaying the data collected when magnesium ribbon and 0.1 M, 2.0 M, and 4.0 M HCl reacted. Label the data runs as well as the overall graph, the x-axis, the y-axis, and include units on the axes. �(11.2)



Data Analysis

1. ☐ Explain any differences between the rate of the baseline reaction and the rate of the reaction with the hydrochloric acid solutions at different temperatures.

2. ☐ Explain the differences between the rate of the baseline reaction and the rate of the reaction with the powdered magnesium.

3. ☐ Explain the differences between the rate of the baseline reaction and the rates of the reactions with different concentrations of HCl.

Analysis Questions

1. **Why is the absolute pressure sensor used in this experiment?**

2. **Why is it important to establish a baseline reaction rate?**

3. **Explain why the slope of the pressure versus time plot can be used to describe the rate of the reaction.**

4. **What combination of treatments available in the laboratory would create the fastest reaction rate between magnesium and hydrochloric acid?**

Synthesis Questions

Use available resources to help you answer the following questions.

1. **List other ways in which the amount of reactants or products present in reactions can be determined realistically and in real time.**

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2. **Why is it important to study rates of reactions?**

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3. **A catalyst is a substance that allows chemical reactions to occur at a lower energy than is normally expected. How do catalysts affect reaction rates? Why?**

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____

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. **In general, the _____________ the concentration of reactants in a reaction, the _________ the rate of the reaction will be.**

   A. Greater; slower
   B. Greater; faster
   C. Lower; faster
   D. No relationship exists

2. **In general, the _____________ the surface area available for reaction is, the _________ the rate of the reaction will be.**

   A. Greater; faster
   B. Greater; slower
   C. No relationship exists
   D. Smaller; faster

3. **In general, the _____________ the temperature of a reaction is, the _________ the rate of the reaction will be.**

   A. No relationship exists
   B. Lower; faster
   C. Greater; slower
   D. Greater; faster

4. **At the molecular level, what needs to happen for reactant particles to form products?**

   A. The reactant particles need to be in an excited state
   B. The reactant particles must have a molar mass greater than 10 g/mol
   C. The reactant particles need to be in the gaseous state
   D. The reactant particles need to collide with sufficient energy

5. **What form of iron will form rust the fastest?**

   A. A galvanized nail
   B. A solid block of iron
   C. Iron filings
   D. All forms of iron form rust at the same rate

Key Term Challenge

Fill in the blanks from the list of words in the Key Term Challenge Word Bank.

1. The part of chemistry that deals with the rates of chemical reactions is called _________________________. Explosions have very _________________________ rates of reactions; while the formation of rust has a very _________________________ reaction rate. _________________________ describes how chemicals react at the molecular level. Collision theory states that the frequency with which reacting particles run into each other determines the rate of the reaction. The greater the number of collisions, the _________________________ the rate of the reaction. The number of collisions can be increased by _________________________ the reactants, _________________________ the concentration of the reactants, or by increasing the particles' _________________________. In contrast, _________________________ any or all of these factors results in a lower reaction rate.

Key Term Challenge Word Bank

Paragraph 1

atomic theory

collision theory

cooling

decreasing

electron energies

electron theory

faster

increasing

kinetics

large

mass

rate laws

slower

small

surface area

thermodynamics

warming