Reaction Rates

Measuring Reaction Rates

Unit 6 - Lesson 3a-b
Measuring Reaction Rates

Students will be able to:
• Write a plan to measure the reaction rate

Core Vocabulary:
Controlled variable, Dependent variable, Independent variable, Gas syringe, precipitate,
Measuring Reaction Rates

Reaction Rate Investigations

• There are three variables which must be considered when investigating the rate of reaction:

• The independent variable – the factor which is being changed. In this case, this will be one of the factors which affect the rate of reaction, e.g. Temperature, surface area, concentration, nature of the reactants and presence of a catalyst. This factor will state a range of values to be tested.

• The dependent variable – the factor which is being measured to obtain some data, in this case, the reaction rate.

• The controlled variables – all other variables which must be kept constant to ensure that the results are reliable.
Practice Problem:
For each of the following hypotheses, identify the independent, dependent and controlled variables:

1. When the surface area of zinc metal is increased, the reaction rate (hydrogen gas production) will also increase.
2. As the temperature of the acid increases, the time taken for the precipitate to form also increases.
3. When the concentration of hydrochloric acid is increased, the rate of gas production also increases.
Measuring Reaction Rates

Practice Problem: Answers Part 1
For each of the following hypotheses, identify the independent, dependent and controlled variables:

1. When the surface area of zinc metal is increased, the reaction rate (hydrogen gas production) will also increase.
   - **Independent Variable:** The surface area of zinc
   - **Dependent Variable:** Reaction rate (hydrogen gas production)
   - **Controlled Variables:**
     - The volume of acid used
     - The concentration of acid used
     - Mass of zinc used
     - Method of gas collection
Practice Problem: Answers Part 2

For each of the following hypotheses, identify the independent, dependent and controlled variables:

2. As the temperature of the acid increases, the time taken for the precipitate to form also increases.

- **Independent Variable:** The temperature of the acid
- **Dependent Variable:** Time taken to form the precipitate
- **Controlled Variables:**
  - The volume of acid used
  - Concentration of acid
  - Volume of thiosulfate (the other) solution used
  - The concentration of thiosulfate (other) solution used
  - Endpoint for reaction
Measuring Reaction Rates

Practice Problem: Answers Part 3

For each of the following hypotheses, identify the independent, dependent and controlled variables:

3. When the concentration of hydrochloric acid is increased, the rate of gas production also increases.
   - **Independent Variable:** Concentration of hydrochloric acid
   - **Dependent Variable:** Rate of gas production
   - **Controlled Variables:**
     - Volume of solution
     - Mass/volume of other reactant
     - Endpoint for the experiment
     - Method of gas collection
Methods to Measure the Reaction Rate

• The method must describe how the independent variable will be changed and how the dependent variable will be measured. The reaction rate can be measured in two ways:
  • How quickly the reactants are used up
  • How quickly the products form

• The rate of reaction is easy to determine if the reaction involves a color change or the formation of a gas.
Measuring Reaction Rates

Reactions which involve a change in color

• The rate of reaction is monitored by determining how quickly the color changes.

Example: The iodine clock reaction

• The iodine clock reaction is the oxidation of iodide ions by hydrogen peroxide. In this reaction, the two clear solutions, one containing iodine (known as solution A) and the other containing starch (known as solution B) react to give a rapid, blue-black color change.
Practice Problem:

• For the example on the iodine clock experiment, identify the three types of variables and write a method to describe how to measure the reaction rate when the temperature of one of the solutions is changed.
Measuring Reaction Rates

Independent Variable:
• The temperature of one of the solutions

Dependent Variable:
• The time it takes for the clear mixture to turn blue-black

Controlled Variables:
• The volume of each solution
• The concentration of each solution
• Whether the solutions are swirled when combined
• Heating the same solution each time
• Rinse and dry glassware after each test
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Method:

- Measure 10ml of each solution into separate measuring cylinders
- Heat the first quantity of solution to 25°C in a water bath.
- Combine with solution B and time until a color change occurs.
- Rinse glassware and dry before repeating with other temperatures.
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Reactions where a gas is produced

- The rate of reaction can be determined by measuring how much gas is produced after a certain time interval (see the setup below).
Measuring Reaction Rates

Example: Hydrogen Gas

• The equation for the reaction between zinc metal and dilute hydrochloric acid is:

\[ \text{Zn} (s) + 2\text{HCl} (\text{aq}) \rightarrow \text{ZnCl}_2 (\text{aq}) + \text{H}_2 (\text{g}) \]

• The hydrogen gas produced can be collected, and its volume measured at specific time intervals. A lit splint can be used to confirm the presence of hydrogen as it will make a 'pop' sound when the splint is placed in near the hydrogen.
Measuring Reaction Rates

Precipitate reactions:

• In reactions where a precipitate is formed over time can be used as a measure of the reaction rate. These reactions require a clear understanding of where the endpoint for the reaction is.

• For example, when sodium thiosulfate reacts with an acid, a cloudy yellow sulfur precipitate is formed. The endpoint for this reaction is when the cross on the under sheet of paper is no longer able to be seen. The reaction is as follows:

\[
\text{Na}_2\text{S}_2\text{O}_3(\text{aq}) + 2\text{HCl}(\text{aq}) \rightarrow 2\text{NaCl}(\text{aq}) + \text{SO}_2(\text{aq}) + \text{H}_2\text{O}(l) + \text{S}(s)
\]
Measuring Reaction Rates

Precipitate reactions:

\[ \text{Na}_2\text{S}_2\text{O}_3(\text{aq}) + 2\text{HCl}(\text{aq}) \rightarrow 2\text{NaCl}(\text{aq}) + \text{SO}_2(\text{aq}) + \text{H}_2\text{O}(l) + \text{S}(s) \]
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Changes in mass:

- The rate of a reaction that produces a gas can also be measured by calculating the mass loss as the gas is formed and escapes from the reaction flask.
Measuring Reaction Rates

Changes in mass:

• This method can be used for reactions that produce carbon dioxide or oxygen, but are not very accurate for reactions that give off hydrogen because the mass is too low for accuracy.

• Measuring changes in mass may also be suitable for other types of reactions such as dissolving of solid substances.
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Delayed Reactions

• Some chemicals will have a delayed reaction if they have a coating over their surface.
• Many metals upon contact with air produce an oxide layer, which slows down the reaction.
• This can be overcome by sanding the metal before using it.
Measuring Reaction Rates

Practice Problem:

Hydrochloric acid and calcium carbonate (marble chip) react according to the following equation:

\[ \text{CaCO}_3 + 2\text{HCl} \rightarrow \text{CaCl}_2 + \text{H}_2\text{O} + \text{CO}_2 \]

Describe in detail, how the rate for this reaction can be increased by changing the concentration of the acid. You must include:

• The independent variable and how it will be changed
• The dependent variable and how it will be measured
• Any relevant controlled variables and how they will be kept the same
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Practice Problem: Answer

Independent variable:
• The concentration of the acid

Dependent variable:
• The reaction rate of calcium carbonate and hydrochloric acid, specifically the amount of gas produced.

Controlled variables:
• The volume of liquid that the calcium carbonate reacts with
• The mass and surface area of calcium carbonate
• Beginning and endpoint of reaction
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Practice Problem: Answer

Method:

• Attach a gas syringe to a stand, boss and clamp.
• Using a measuring cylinder, add 50 cm$^3$ of dilute hydrochloric acid to a conical flask.
• Using a balance, weigh and then add 1 g of calcium carbonate to the flask. Immediately connect the gas syringe and start the stopwatch.
• Record the volume of gas produced every 10 seconds until the reaction is finished (i.e. no more fizzing is heard, and the gas volume is no longer increasing).
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Practice Problem: Answer

Method:

• Repeat steps 1 to 5 with different concentrations of hydrochloric acid. Different concentrations of acids can be made using the following:

  • 40 cm$^3$ HCl and 10 cm$^3$ water (80% concentration)
  • 30 cm$^3$ HCl and 20 cm$^3$ water (60% concentration)
  • 20 cm$^3$ HCl and 30 cm$^3$ water (40% concentration)
  • 10 cm$^3$ HCl and 40 cm$^3$ water (20% concentration)
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Data Processing

- Data collected from an investigation is typically displayed as both a table and a graph.
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Example: Rate of Hydrogen gas Production
When a magnesium ribbon dissolves in an acid, hydrogen gas is produced. The equation for this reaction is as follows:

$$\text{Mg}(_{\text{s}}) + 2\text{HCl}(_{\text{aq}}) \rightarrow \text{MgCl}_2(_{\text{aq}}) + \text{H}_2(_{\text{g}})$$

The results from this experiment are displayed below:

<table>
<thead>
<tr>
<th>Time from start (s)</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>55</th>
<th>60</th>
<th>65</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume of gas collected (mL)</td>
<td>0</td>
<td>15</td>
<td>26</td>
<td>34</td>
<td>40</td>
<td>45</td>
<td>50</td>
<td>53</td>
<td>56</td>
<td>57</td>
<td>59</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>
Measuring Reaction Rates

Example: Rate of Hydrogen gas Production

Volume of Gas Produced (mL) Over Time (s)

Highest reaction rate

Reaction finish
Measuring Reaction Rates

A typical rate of reaction graph:

- Begins rapidly with a steep initial slope.
- Slows down as time progresses, the slope of the graph becomes less steep as the reaction progresses. This is due to the concentration of the reactants decreasing.
- Stops after a particular time. This is seen as the slope leveling out, indicating that one or both reactants have been used up.
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Calculating the Rate of Reaction from a Graph

• The gradient of the graph is equal to the rate of reaction \( y \) at a specific point in time \( x \).

• Therefore, rate of reaction can be calculated using the equation:

\[
\text{Rate of reaction} = \frac{y}{x}
\]
Measuring Reaction Rates

For Example:

• The graph below shows the reaction rate of a metal with acid.

![Graph](image)

• Reaction rate at 50 seconds can be calculated by:
• \( \frac{58 \text{ cm}}{50 \text{ s}} = 1.16 \text{ cm}^3/\text{s} \)
Measuring Reaction Rates

Practice Problem:

• The volume of carbon dioxide that is produced during the reaction is measured at different times over ten minutes.

• The results are shown in the table to the right.

<table>
<thead>
<tr>
<th>Time (mins)</th>
<th>The volume of CO₂ produced (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td>26</td>
</tr>
<tr>
<td>3</td>
<td>36</td>
</tr>
<tr>
<td>4</td>
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<td>6</td>
<td>58</td>
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<td>65</td>
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<td>8</td>
<td>70</td>
</tr>
<tr>
<td>9</td>
<td>74</td>
</tr>
<tr>
<td>10</td>
<td>77</td>
</tr>
</tbody>
</table>
Measuring Reaction Rates

Practice Problem:

1. Use the data in the table to draw a graph showing the volume of gas that is produced in the reaction, over 10 minutes.

2. At which of the following times is the reaction fastest?
   Time = 1 minute; time = 6 minutes or time = 8 minutes.

3. Suggest a reason why the reaction slows down over time.

4. If the experiment was repeated using a more concentrated hydrochloric acid solution:
   a) Would the rate of the reaction increase or decrease from the one shown in the graph?
   b) Give a reason for your answer
   c) Draw a line on the graph to show how you would expect the reaction to proceed with a more concentrated HCl solution.
Measuring Reaction Rates

Practice Problem: Answers part 1

1. Use the data in the table to draw a graph showing the volume of gas that is produced in the reaction, over 10 minutes.

![Graph showing volume of CO2 produced over time](image-url)
2. At which of the following times is the reaction fastest?

Time = 1 minute; time = 6 minutes or time = 8 minutes.
Measuring Reaction Rates

Practice Problem: Answers part 3

3. Suggest a reason why the reaction slows down over time.

Reactants have turned into products, so there are fewer collisions occurring per unit time.
Measuring Reaction Rates

Practice Problem: Answers part 4

4. If the experiment was repeated using a more concentrated hydrochloric acid solution:
   a) Would the rate of the reaction increase or decrease from the one shown in the graph?
      The rate would increase
   b) Give a reason for your answer
      The higher number of acid molecules in the same volume means that there would be more collisions in the same amount of time and more of these are likely to be effective, thus an increased rate of reaction.
4. If the experiment was repeated using a more concentrated hydrochloric acid solution:
   
c) Draw a line on the graph to show how you would expect the reaction to proceed with a more concentrated HCl solution.