Lesson Plan: Reaction Mechanisms

FOR THE TEACHER

Summary
In this lesson students explore reaction mechanisms and their connection to rate laws and energy profile graphs through a game, relay race, and finally a chemical demonstration.

Grade Level
High School (AP Chemistry)

NGSS Alignment
This lesson will help prepare your students to meet the performance expectations in the following standards:

- **HS-PS1-4**: Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.

- **Scientific and Engineering Practices**:
  - Using Mathematics and Computational Thinking
  - Analyzing and Interpreting Data
  - Engaging in Argument from Evidence

AP Chemistry Curriculum Framework
This lesson supports the following unit, topics and learning objectives:

- **Unit 5: Kinetics**
  - **Topic 5.1**: Reaction Rates
    - **TRA-3.A**: Explain the relationship between the rate of a chemical reaction and experimental parameters.
  - **Topic 5.3**: Concentration Changes Over Time
    - **TRA-3.C**: Identify the rate law expression of a chemical reaction using data that show how the concentrations of reaction species change over time.
  - **Topic 5.4**: Elementary Reactions
    - **TRA-4.A**: Represent an elementary reaction as a rate law expression using stoichiometry.
  - **Topic 5.5**: Collision Model
    - **TRA-4.B**: Explain the relationship between the rate of an elementary reaction and the frequency, energy, and orientation of molecular collisions.
  - **Topic 5.6**: Reaction Energy Profile
    - **TRA-4.C**: Represent the activation energy and overall energy change in an elementary reaction using a reaction energy profile.
  - **Topic 5.7**: Introduction to Reaction Mechanisms
    - **TRA-5.A**: Identify the components of a reaction mechanism.
  - **Topic 5.8**: Reaction Mechanism and Rate Law
    - **TRA-5.B**: Identify the rate law for a reaction from a mechanism in which the first step is rate limiting.
  - **Topic 5.9**: Steady-State Approximation
    - **TRA-5.C**: Identify the rate law for a reaction from a mechanism in which the first step is not rate limiting.
  - **Topic 5.10**: Multistep Reaction Energy Profile

Submitted by
Melissa Hemling
Beaver Dam High School
Beaver Dam, Wisconsin

Thanks to:
2018 AACT AP Content Writing Team
- **TRA-5.D:** Represent the activation energy and overall energy change in a multistep reaction with a reaction energy profile.

  - **Topic 5.11:** Catalysis
    - **ENE-1.A:** Explain the relationship between the effect of a catalyst on a reaction and changes in the reaction mechanism.

**Objectives**

By the end of this lesson, students should be able to

- Apply Collision Theory to explain the importance of the rate determining step and catalysts.
- Identify key parts of a Reaction Mechanism such as rate determining step, intermediates, catalysts, proposed rate law, and reaction profile graph.
- Justify the validity of a proposed mechanism.

**Chemistry Topics**

This lesson supports students’ understanding of

- Kinetics
- Reaction Rate
- Collision Theory
- Reaction Mechanisms
- Rate Determining Step
- Catalysts

**Time**

- **Teacher Preparation:** 30 minutes to set up demonstration
- **Lesson:** 240 minutes
  - 60 minutes: *Hungry Hungry Hippo Collisions Activity*
  - 90 minutes: *Kinetic Relay Race Activity*
  - 90 minutes: *Is it Valid? Activity*

**Materials**

**Hungry Hungry Hippo Collisions Activity:**

- Hasbro’s Hungry Hungry Hippo Game (1 per class or per group)
  - Traditional 4 player game, or 2 player Grab and Go travel game
  - Alternative: Teachers could show a video of people playing the game if none are available for use (see teacher notes below).
  - Alternative: You can conduct life-sized version of game (see teacher notes below).
- Computer projection and internet to play a YouTube Video
- *Optional:* **Pop Beads** (3 beads in three different colors for each student or group)

**Kinetic Relay Race Activity:**

- Stop watch (1 per group)
- Masking tape (1 roll to share with entire class)
- Colored pencils or markers
- Relay materials vary based on availability (see teacher notes below).
  - Examples of Relay Race supply combinations (per group of four):
    - Ping pong ball, racket, spoon, and masking tape, OR
    - Textbook and backpack, OR
    - 2 tennis balls, pantyhose, and racket

**Is it Valid? Activity:**

- **Elephant toothpaste demo**
  - 20 ml **Hydrogen peroxide, 30%**
o 5ml, 2M Sodium iodide solution
o 10ml Dawn dishwashing liquid
o 100 mL Graduated cylinder or Erlenmeyer flask
o Tray at least 1 inch deep (to collect the foam)

Note: Chemical supply companies like Flinn Scientific sell chemical demonstration kits of this demo called “Old Foamey” or “Elephant Toothpaste” for about $25-30

Note: A safer version of this demo is available through AACT, Giant Toothpaste, and can be used as a student lab.

Computer with internet access to watch a YouTube Video

Safety (For “Is it Valid?” Activity)

- Students should wear proper safety gear during chemistry demonstrations. Safety goggles and lab apron are required.
- Wear appropriate chemical splash goggles, chemical-resistant gloves and a chemical-resistant apron.
- Hydrogen peroxide, 30% will act as an oxidizing agent with practically any substance. This substance is severely corrosive to the skin, eyes, and respiratory tract; a very strong oxidant; and a dangerous fire and explosion risk. Do not heat this substance. Consult the SDS for additional safety, handling, and disposal information.
- Sodium iodide is slightly toxic by ingestion. Consult the SDS for additional safety, handling, and disposal information.
- Although the dishwashing liquid is considered non-hazardous, do not ingest the material.
- Do not stand over the reaction; steam and oxygen are produced quickly. The reaction gets hot.

Teacher Information

- Reaction Mechanism Background Information for the Teacher:
  o Bozeman Science Kinetics Video Playlist
  o Khan Academy Reaction Mechanism Video Playlist

Hungry Hungry Hippo Collisions Activity:

- The goal of this introductory activity is for students to use their prior knowledge of a common kid’s game and apply it to collision theory. Understanding collision theory will set the stage for why reactions do not usually occur in one step, rather in multi-step mechanisms
- This activity assumes that students understand the basics of chemical reactions (reactants/products) and bonds. Reaction Profile and Maxwell-Boltzmann graphs are included in the activity and briefly explained. However, it may be beneficial for students to have exposure with these types of graphs before the activity. Make sure to look over the activity to decide if your students have the prior knowledge necessary to complete this activity. If not, please discuss concepts they might be missing beforehand.
- This activity is written for a whole class activity or as groups of 2 or 4. It can be modified to fit your needs based on access to Hungry Hungry Hippo games
  o Hungry Hungry Hippo games can be found at rummage sales, toy stores, or Amazon. A traditional 4 player version of the game sells for about $20 new and the travel 2 player version of the game sells for about $10 new.
  o A round of Hungry Hungry Hippo only lasts 1-2 minutes.
  o (Optional) You may offer small prizes or certificates to the winner(s).
- Options for game play:
  o Groups of 4 or 2 play to find a winner. 1 game per group is needed.
  o Do a Hungry Hippo Elimination Tournament to find the ultimate winner in the class. Ideally 1 game per group is needed so multiple games could be played at once.
  o Select 2 or 4 players to play in front of the class. Only one game needed.
  o Watch a YouTube video of others playing Hungry Hungry Hippos if no games are available. 2009 Hungry Hippo commercial video
You may opt to play a human-sized version of the game in the gym. Some schools do this as a homecoming activity. In this case, each group will need access to helmet, swivel scooter, rope, trash basket. A large pile of balloons will also be needed. Refer to this [video of game play](#) and [example rules](#).

- **Note:** The activity asks students to also consider a Red Rover game they may have played in elementary school. Some elementary school have “banned” this game due to potential of injury. Instead of playing this game, students are asked to watch a comedic YouTube clip of the International Red Rover Championships.
  - It is a good idea to remind your students about what the game of Red Rover is before you show the video. [Rules to Red Rover](#) for reference.
  - Red Rover YouTube video to show to class. The video is 2 min and 35 seconds.
  - Please preview the video before showing. However, you may choose just discuss the game of Red Rover if the video does not fit your style.
  - You may choose to play or act-out Red Rover., but please consider the potential for injury.

**Format of Activity:**
- First, students play or watch a Hungry Hungry Hippo game.
- Next, students reflect and make connection to collision theory by answering guided questions in groups of 2-4 on their handout.
- Then, students apply their knowledge to another game like Red Rover (via video) and consider other analogies.
- Finally, students consider a chemical reaction and answer questions about the likelihood of a reaction occurring in one step versus many steps. This idea of mechanisms and elementary steps are introduced.
- The guided questions in this activity are written for students to work in collaborative groups of 2-4 with a teacher actively facilitating and checking understanding throughout.
- Visit the [POGIL website](#) for more information about implementing a guided inquiry activity in your classroom and consult their [implementation guide](#).
- It is very important that the instructor frequently checks in with groups to check answers as the questions build off of one another.

**Additional Suggestions:**
- You may just look over student’s shoulders or eavesdrop on conversations to quietly monitor progress and step-in when groups get confused.
- You may have groups check in with you after key questions to check multiple questions at once.
- You may decide to have a whole-class discussion after each Model to confirm accuracy and understanding.
- If groups are confused, step in and help guide them to a correct understanding through a private conversation or whole class discussion.
- If time is short, you may skip questions 9 and 10 without sacrificing too much content.
- At Question #11, you may opt for students to act out the processes with pop beads. This may help their understanding of the particulate nature of the different types of elementary steps. The goal if you students to see and feel how unlikely a termolecular step is compared to a unimolecular or bimolecular step.
  - Students pull apart two pop beads for a unimolecular step
  - Students put together two pop beads for a bimolecular step
  - Students try to put together three pop beads at once for a termolecular step (very hard compared to the others)
  - You may also choose to act out the Read This! box before Question #12 with the pop beads to show how a two step process of building the product ABC is “easier” than doing it all at once.

- At the end of the activity, have a whole class discussion about the answers to the questions, collision theory, and mechanisms. The teacher should emphasize how molecules need to collide
with the right orientation and with sufficient energy to overcome the activation energy barrier in order to break bonds and react. It is very unlikely that three molecules (termolecular) would collide at the same time with sufficient energy and at the right orientation in order to break bonds. However, unimolecular or bimolecular reactions are more likely and therefore elementary steps and mechanisms are used to describe reactions. It might be a good idea for students to add to their Conclusion summary after the whole class discussion.

- **Image sources:**
  - [Hungry Hungry Hippo Game](https://creativecommons.org/licenses/by-sa/2.0): By Dave Fischer (originally posted to Flickr as Hungy Hippos!) [CC BY-SA 2.0](https://creativecommons.org/licenses/by-sa/2.0), via Wikimedia Commons
  - All other diagrams were drawn by the author, Melissa Hemling

**Kinetic Relay Race Activity**

- The goal of this activity is to build on the previous collision theory activity and develop the concept of rate determining step. Students will complete a relay race to model a multi-step reaction mechanism with a slow, rate-determining step. The race will be modified to show the effects of a catalyst.
- Relay teams should be groups of 4. One person is a timer and the 3 others will run a lap of the relay race.
- If your classroom is not conducive to a relay race, reserve a gym, hallway, or go outside.
- You may offer prizes for the fastest relay team or make it into a competition so that all members try hard. It is key that lap 1 is hard/slow and laps 2 and 3 are fast. Data will be thrown off if a group member does not try hard in laps 2 or 3 and they end up being longer than lap 1.
- **Relay Race Options:**
  - Mark the start and finish lines with masking tape (or use lines on floor if in gym)
  - Each team needs a stop watch (cellphone timers could also be used) and a designated timer to time each lap and record the data. Students who are unable to participate in the relay due to injury, attire, illness, or lack of athletic interest should be encouraged to be the timer.
  - The other 3 group members will run the 3 laps of the relay. The relay will be run two times. The first round will be normal and in the second round, Lap 1 will be modified to make it much easier/faster to show the effect of a catalyst.
  - Materials will vary based on what you have available at your school. Consult your physical education teachers to borrow supplies. What matters is that the first lap of the relay is slow and will take a long time to complete (rate-determining step) while the last two laps are fast and easy. In the second round of the relay race, lap 1 will be modified to make it easier/faster (catalyst).
- **Example Relays (Pick one and feel free to modify as needed):**
  - **Tennis ball relay**
    - Materials per group: 2 tennis balls, pantyhose, tennis racket
    - Lap 1: Before the timer starts, place one tennis ball into the foot of one leg of the pantyhose. Put the panty hose over your head like a hat with the empty leg tucked into their shirt. The leg containing the tennis ball should swing in front of the person (see this [Minute to Win It Elephant March game](https://www.youtube.com/watch?v=8fF8sH1VgIY) for help). When the timer starts, the person should swing their head so that the tennis ball in the pantyhose swings. They will use the tennis ball in the pantyhose to try to move the other tennis ball and make it roll across the room (hard).
    - Lap 2: Use a tennis racket to roll the loose tennis ball across the room (easy).
    - Lap 3: Carry the loose tennis ball the length of the room under their armpit (easy).
    - Catalyst option: Instead of just swinging the pantyhose/tennis ball combo with their head, they may use their hands to help the pantyhose/tennis ball combo hit the loose tennis ball.
  - **Ping pong ball relay:**
Materials per group: Ping pong ball, spoon, racket, tape,

Lap 1: Ping pong ball carried the length of the room on a spoon that is held in the mouth (hard - like a spoon race).

Lap 2: Ping pong ball is carried the length of the room balancing on a tennis racket (easy).

Lap 3: Ping pong ball is carried the length of the room under the person’s armpit (easy).

Catalyst option: Masking tape is rolled into a circle and used to stick the ping pong ball to the spoon for lap 1 to make it quicker/easier.

Textbook relay

Materials per group: Textbook, backpack

Lap 1: Textbook is carried the length of the room by carefully balancing it on the person’s head without touching it (hard).

Lap 2: Textbook is carried the length of the room by carrying it in the backpack (easy).

Lap 3: The textbook is carried the length of the room by carrying it using one arm (easy).

Catalyst option: The group member is allowed to hold the textbook on top of their head to make lap 1 quicker/easier.

Format of activity:

First, conduct the relay. Time each lap and the overall time. Record in the data table on the handout.

Second, conduct the second relay with the catalyst option. The instructor will describe the modification like using tape or hands and the teams will decide which lap to do the modification to. The goal is for teams to decide on their own that applying the modification to lap 1 will speed the relay up the most. Time each lap and the overall time. Record in the data table on the handout.

Next, answer the guided questions on the handout to help students reflect and make connections between the relay and reaction mechanisms.

The guided questions in this activity are written for students to work in collaborative groups of 2-4 with a teacher actively facilitating and checking understanding throughout.

Visit the POGIL.org website for more information about implementing a guided inquiry activity in your classroom and consult their implementation guide.

It is very important that the instructor frequently checks in with groups to check answers as the questions build off of one another.

Additional Suggestions:

You may just look over student’s shoulders or eavesdrop on conversations to quietly monitor progress and step-in when groups get confused.

You may have groups check in with you after key questions to check multiple questions at once.

You may decide to have a whole-class discussion after each Model to confirm accuracy and understanding.

If groups are confused, step in and help guide them to a correct understanding through a private conversation or whole class discussion.

Have a whole class discussion where students share out their conclusions and answers. It might be a good idea for students to add to their Conclusion summary after the whole class discussion.

All diagrams were drawn by the author, Melissa Hemling

Is it Valid? Activity

The goal of this activity is to connect a real chemical reaction (demo) with proposed mechanisms to confirm validity. This activity builds off of the last activity (Kinetic Relay Race).

Students should know how to determine the rate law for a reaction based on integrated rate law graphs and data before completing this activity.

The classic Elephant toothpaste demo will be performed. Click on the hyperlink for directions or use google to find different variations. Many teachers already perform this demonstration. This demonstration could be saved for this guided inquiry activity.
- ALWAYS practice a demonstration prior to attempting in front of students.
- A safer version of this demo is available through AACT and can be used as a student lab (Giant Toothpaste).
- Note: If you do not have the supplies or are not comfortable with this demonstration, you may show a YouTube video of it. Make sure to point out to the students the hydrogen peroxide without the catalyst (does nothing) versus when the catalyst is added. Some options are below:
  - Jimmy Kimmel Live
  - Local Morning Show Scientist
  - Flinn Elephant Toothpaste (better for teacher reference)
- Format of Activity:
  - First, the instructor will perform the Elephant Toothpaste demo. This is done as a demo as the danger of 30% hydrogen peroxide is high. Consult the SDS for additional safety, handling, and disposal information.
  - Next, students will analyze this demo through the lens of collision theory ad reaction mechanisms
  - Finally, students will consider what makes a mechanism “valid.”
  - The guided questions in this activity are written for students to work in collaborative groups of 2-4 with a teacher actively facilitating and checking understanding throughout.
  - Visit the POGIL.org website for more information about implementing a guided inquiry activity in your classroom and consult their implementation guide.
  - It is very important that the instructor frequently checks in with groups to check answers as the questions build off of one another.
- Additional Suggestions:
  - You may just look over student’s shoulders or eavesdrop on conversations to quietly monitor progress and step-in when groups get confused.
  - You may have groups check in with you after key questions to check multiple questions at once.
  - You may decide to have a whole-class discussion after each Model to confirm accuracy and understanding.
  - If groups are confused, step in and help guide them to a correct understanding through a private conversation or whole class discussion.
- Students will be asked to watch a YouTube video of a platinum catalyst decomposing hydrogen peroxide to clean contact lenses. Here is the link to the video of this process. You may opt to watch as a class or have students watch individually. Please preview the video before showing.
- Extension:
  - Question 9 references the catalase enzyme. You could have students do a quick experiment with store-bought 3% hydrogen peroxide and catalase (dry yeast or liver) to see the bubbles of oxygen produced from this catalyst.
  - See sample lab. Students should wear proper safety equipment including googles, gloves, and aprons.
  - Note: the concentrations of hydrogen peroxide in the teacher demo and this lab are very different. It is important to tell you students as catalase is a more effective catalyst than iodide.
- After the activity:
  - Have a whole class discussion where students share out their conclusions and answers. It might be a good idea for students to add to their Conclusion summary after the whole class discussion.
  - Have students complete a released free response question concerning reaction mechanisms.
  - Free Response Question #5 c-f from 2013
    - Free Response questions from 2013
    - Scoring Guide
  - Free Response Question #2 Form B from 2008
- Free Response questions from 2008 Form B
- Scoring guide
  - Free Response Question #6 f-h Form B from 2010
- Scoring Guide
- All diagrams were drawn by the author, Melissa Hemling