Answer Key: Hungry Hungry Hippo Collisions

Background
In order for a reaction to occur, molecules must collide to break bonds. Not all collisions result in the breaking of bonds and the production of products, however. In this activity you will embrace your inner-child and consider various children’s games as an analogy for collision theory.

Problem
What makes a collision successful in producing products?

Hungry Hungry Hippos Game

Hungry Hungry Hippos is a children’s game where four players press a lever on their mechanical hippo to lift up the hippo’s mouth and grab a marble from the middle of the board. All four player’s hippos fight over a group of marbles simultaneously. The player with the hippo that “eats” the most marbles wins.

Play a game of Hungry Hungry Hippos according to your Instructor’s guidelines. While playing, pay close attention to the successful strategy used to win and obtain the most marbles.

Guided Questions

1. Describe a successful strategy used to win the Hungry Hungry Hippo game. Consider motion of the hippo’s head and lever in your answer.

   Answers will vary
   The lever is pressed at a steady, quick pace.
   The lever is not pressed too fast as the head won’t lift high enough
   The hippo’s head must lift higher than the marble
   The hippo’s head must come into contact with the marble at the front of the nose to grab it
   Wait for marble to come close to hippo’s head before pressing lever
Read This!

Activation Energy
When considering a successful molecular collision that will result in reactant bonds breaking and the formation of new products, one must consider Collision Theory. Collision theory helps chemists explain why reaction rates differ for different reactions. Collision theory states that when reactant molecules collide, only a certain fraction of the collisions cause a chemical change.

One variable that affects whether a collision will be successful in breaking bonds is Activation Energy, $E_a$. Activation energy is the minimum energy required to undergo a specific reaction. If the energy of the collision is larger than the reaction’s activation energy ($E_a$), bonds will break and the reaction will occur. If the energy of the collision is less than the reaction’s activation energy, bonds will not break and the reaction will not occur.

2. Consider the Hungry Hungry Hippo game as an analogy for a chemical reaction and collision theory. What part of the game demonstrates the following statement from collision theory: **A successful collision requires more energy than the activation energy**? Explain why.

The lever needs to be pushed hard enough for the hippo’s head to rise. If it is not pressed hard enough (with enough energy), the head will not rise and a marble cannot be captured. The activation energy represents the minimum pressure needed on the lever to lift the hippo’s head.

Model 1: Activation Energy

Reaction Profile Graphs

Maxwell-Boltzmann Distributions
3. Analyze the graphical representations of activation energy, $E_a$, in Model 1.
   a. Which type of graph (Reaction Profile or Maxwell-Boltzmann) shows the proportion of molecule with enough energy to overcome the activation energy barrier and break bonds?

   Maxwell-Boltzmann

   b. Which magnitude activation energy (25, 50, or 100 kJ/mol) has the largest proportion of molecules with enough energy to break bonds? Why do you think that is?

   25 kJ/mol because it is a low energy and more molecules have a kinetic energy higher than that.

   c. Does the enthalpy of the reaction (endothermic or exothermic) have a direct relationship on activation energy? Describe how you know using evidence from Model 1.

   No. There is an endothermic and exothermic reaction profile graph, both with 50 kJ/mol activation energy.

   d. Consider the Hungry Hungry Hippo Game and analogy for collision theory. Describe differences in a Hungry Hungry Hippo game in which one round has an activation energy of 100 kJ/mol and the second round has an activation energy of 25 kJ/mol.

   Answers will vary. The first round would have a lever that requires more energy to push the Hippo’s head up because it is rusty or sticky. The second round would have a lever that requires less energy to push the Hippo’s head up because it is well oiled or greased up. Students could also mention that the mass of the Hippo’s head could be heavier in round one and lighter in round two.

Read This!

Orientation
Another variable that affects whether a collision will be successful in breaking bonds is the orientation of the collision. Only if molecules collide in the correct direction (with the correct angle and type of atoms colliding) will bonds break and products form.
4. What part of the Hungry Hungry Hippo game demonstrates the following statement from collision theory: A successful collision requires reactant molecules to collide in the right orientation? Explain why.

The marble has to be at the nose of the hippo’s head in order for the hippo to capture it. The hippo’s head also has to rise up higher than the marble to capture it. If the marble or hippo’s head is in another orientation, the marble will not be captured similar to the orientation factor of collision theory.

Read This!

Putting it all Together

Only if molecules collide in the correct orientation and with more energy than the reaction’s activation energy will bonds break and products form.
At a given temperature, molecules are moving with different energies according to the Maxwell Boltzmann Distribution graph. Only a certain proportion of the molecules at a given temperature will have enough energy to overcome the activation energy barrier. Increasing temperature does not change the activation energy or the orientation needed to create a successful collision. It does, however, increase average kinetic energy and the frequency of collisions. This in turn increases the probability of a successful collision occurring with more energy than the activation energy and with the correct orientation to break bonds and create new products.

5. How does increasing temperature increase the probability of a successful reaction without changing the activation energy? Explain two reasons why.

Molecules at higher temperatures move with more kinetic energy on average so there are a high proportion of molecules with kinetic energy larger than the activation energy. Temperature does not change activation energy, rather it allows more molecules to overcome the activation energy barrier. The molecules are also moving faster at higher temperatures, increasing the frequency of collisions and the probability that a collision will have the right orientation and enough energy to produce a successful collision.

6. List other variables that speed up a reaction by increasing the frequency of collisions and do NOT change the activation energy.

Increasing concentration, increasing pressure of gaseous reactants, and increasing surface area. Some students may mention mixing/stirring.
7. Consider the Hungry Hungry Hippo Game and analogy for collision theory. Describe differences in a Hungry Hungry Hippo game in which one round occurs at a temperature of 50 K and the second round occurs at a temperature of 100 K. Be sure to explain what would be similar and different between the two rounds.

A 50 K, the player would be hitting the lever less frequently and with less force than the 100 K round. The rest of the variables would stay the same, including the force required to press the lever to make the Hippo’s head rise (activation energy).

8. What is a limitation to the Hungry Hungry Hippo analogy of collision theory?

Answers will vary. Sometimes 2 marbles are captured at a time. Marble motion is not completely random. Energy placed on lever each time it is pressed is not distributed like the Maxwell Boltzmann Distribution graph. Bonds not broken during the capture of the marble.

Red Rover Game

Red Rover is a playground game where two teams (A and B) form separate lines by holding hands. The two lines face each other across the playground. Team A calls out, “Red rover, red rover, let Johnny come over.” Johnny from Team B runs toward Team A’s line and tries to break through the line. If Johnny is successful in breaking through the line, the team earns points. Play continues with Team B calling over someone from Team A to try to break through the line, etc.

Watch the following video “International Red Rover Championships” (https://www.youtube.com/watch?v=9GIyM4tdK2Y) to help answer the following questions.

9. Apply your understanding of Collision Theory to another game like Red Rover after watching the video clip.
   a. Describe why the first round of Red Rover was not a successful collision in terms of collision theory.

   The player that tried to break through the line had enough energy to overcome the activation energy barrier but collided in the wrong orientation (leading with the left knee).

   b. Describe with the final round of Red Rover was a successful collision in terms of collision theory.

   The player that broke through the line had more energy than the activation energy (energy holding the line or bond together) and collided with the right orientation (not leading with the left knee). Since both requirements were met, the collision was successful in breaking the bond or through the line.
c. Describe a limitation to using Red Rover as an analogy for collision theory.

*Answers will vary. In Red Rover, many orientations could work. Orientation is not as important as amount of energy in this game and it should be equally as important. The activation energy changes depending on type of player and hand hold. It is not uniform for the game or reaction.*

10. Describe another game or activity that could be used as an analogy for collision theory. Describe any limitations to the analogy selected.

*Answers will vary. Pinball, playing catch, bowling, darts, bumper cars, etc. Limitations will be similar to the limitations listed in the above games (questions 2c and 3c).*

11. Which reaction will occur **less** often than the other two? Select a, b, or c. Justify your selection based on collision theory.

   a. One reactant splitting up in an unimolecular reaction (A → product)
   b. Two reactant molecules colliding in a bimolecular reaction (A + B → product)
   c. Three reactant molecules colliding in a termolecular reaction (A + B + C → product)

*C (termolecular) will occur less often because the likelihood of all three molecules colliding with a sufficient amount of energy and in the correct orientation is less than two colliding or one splitting apart.*
Read This!

**Reaction Mechanisms**

Sometimes the same chemical process can be represented in different ways. A series of simple *elementary steps* can be used to describe a possible chemical process. These elementary steps may be more likely to happen based on collision theory principles. One reactant splitting (*unimolecular*) or two reactants molecules colliding (*bimolecular*) has a higher probability of colliding in the right orientation with enough energy to overcome the activation energy barrier compared to three reactant molecules colliding (*termolecular*). A series of elementary steps that add up to an overall reaction is called a *Reaction Mechanism*. 

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**One Step Reaction**

\[ A + B + C \rightarrow ABC \]

**Termolecular Reaction**

**Multi-Step Reaction Mechanism**

\[ A + B \rightarrow AB \]
\[ AB + C \rightarrow ABC \]

**Bimolecular Elementary Step #1**

**Bimolecular Elementary Step #2**

\[ A + B + C \rightarrow ABC \]

**Overall Reaction**

**Bimolecular Elementary Step #1**

**Bimolecular Elementary Step #2**
12. Analyze the diagram above, describe any similarities and differences between one-step reactions and multi-step reaction mechanisms.

They both share the same overall reaction and have the same enthalpy (endothermic). Each step is represented by a “hump” in the reaction profile graph with reaction mechanisms having multiple steps (humps). The activation energy of the reaction mechanism is generally smaller than the one step reaction and thus more molecules will be able to overcome the activation energy barrier.

**Model 2: Reaction Mechanism**

<table>
<thead>
<tr>
<th>Chlorination of Methane</th>
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</thead>
<tbody>
<tr>
<td><strong>Process A</strong></td>
</tr>
<tr>
<td>One-Step Reaction</td>
</tr>
<tr>
<td>( \text{CH}_4 + 2 \text{Cl}_2 \rightarrow \text{CH}_3\text{Cl} + \text{HCl} + \text{Cl}^- )</td>
</tr>
<tr>
<td>( \text{CH}_3\text{Cl} + \text{Cl}_2 \rightarrow \text{CH}_3\text{Cl} + \text{Cl}^- )</td>
</tr>
</tbody>
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13. Consider the chart above and answer the following questions.

a. What is the key difference between process A and B?

   *A is written in one reaction. B is written using 2 reactions.*

b. Process B is composed of two elementary reactions. When the two reactions are added together, does it match the one-step reaction in process A? If so, show how the chemical species add or cancel to derive the overall reaction.

   *Yes.*

   \( \text{CH}_4 + \text{Cl}_2 \rightarrow \text{CH}_3 + \text{HCl} \)

   \( \text{CH}_3 + \text{Cl}_2 \rightarrow \text{CH}_3\text{Cl} + \text{Cl}^- \)

   \( \text{CH}_4 + 2 \text{Cl}_2 \rightarrow \text{CH}_3\text{Cl} + \text{HCl} + \text{Cl}^- \)

c. Which process is more likely for the chlorination of methane? Select A or B. Justify your selection based on collision theory.

   *B. Each elementary step or reaction in process B is bimolecular (two molecules colliding) whereas in process A the reaction is termolecular (three molecules colliding) which is less likely to occur with sufficient energy and correct orientation.*

d. Describe what a reaction profile graph would look like for the reaction mechanism (Process B).

   *The reaction profile graph would have two “humps” – one for each step. The activation energy for these steps will be lower than the one step process.*
Conclusion
In your own words, summarize the requirements of collision theory and how they are related to reaction mechanisms.

Answers will vary. Collision theory states two requirements are needed for a successful collision that will break bonds and form products: (1) Molecules collide with more energy than the activation energy for that reaction and (2) Molecules collide in the correct orientation. It is more likely that two molecules will collide with sufficient energy to overcome the activation energy barrier and in the correct orientation than when three or four molecules have to collide at once. Therefore, reactions often occur multi-step processes with elementary steps that are unimolecular or bimolecular as they are more likely to produce a successful collision.