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.
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.

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**Model 1: Activation Energy**

![Reaction Profile Graphs](image)

**Maxwell-Boltzmann Distributions**

![Diagram showing the distribution of kinetic energy with $E_a$ as the minimum energy required for reaction.]
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 molecules with enough energy to overcome the activation energy barrier and break bonds?

   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?

   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.

   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.

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**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.

![Diagram showing orientation of collision](image)
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.

**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.

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

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

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**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](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.

   b. Describe with the final round of Red Rover was a successful collision in terms of collision theory.
c. Describe a limitation to using Red Rover as an analogy for collision theory.

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

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)
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**.
12. Analyze the diagram above, describe any similarities and differences between one-step reactions and multi-step reaction mechanisms.

Model 2: Reaction Mechanism

<table>
<thead>
<tr>
<th>Chlorination of Methane</th>
</tr>
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<tbody>
<tr>
<td>Process A</td>
</tr>
<tr>
<td>One-Step Reaction</td>
</tr>
<tr>
<td>CH₄ + 2 Cl₂ → CH₃Cl + HCl + Cl⁻</td>
</tr>
<tr>
<td>Process B</td>
</tr>
<tr>
<td>Multi-Step Reaction Mechanism</td>
</tr>
<tr>
<td>CH₄ + Cl₂ → CH₃ + HCl</td>
</tr>
<tr>
<td>CH₃ + Cl₂ → CH₃Cl + Cl⁻</td>
</tr>
</tbody>
</table>

13. Consider the chart above and answer the following questions.
a. What is the key difference between process A and B?

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.

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

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

In your own words, summarize the requirements of collision theory and how they are related to reaction mechanisms.