Name: Ishaan Patel Date: February 24, 2022

Student Exploration: Collision Theory

Vocabulary: activated complex, catalyst, chemical reaction, concentration, enzyme, half-life, molecule, product, reactant, surface area

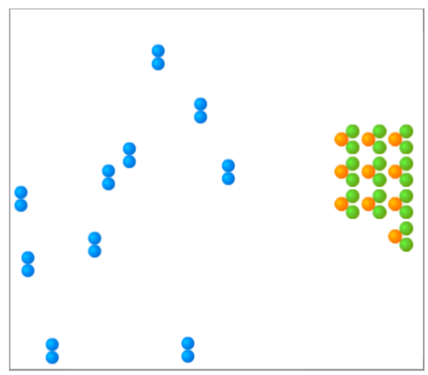
Prior Knowledge Questions (Do these BEFORE using the Gizmo.)

1. Suppose you added a spoonful of sugar to hot water and another to ice-cold water. Which type of water will cause the sugar to dissolve more quickly? Hot Water

2. Suppose you held a lighted match to a solid hunk of wood and another match to a pile of wood shavings. Which form of wood will catch fire more easily? Wood Shavings

Gizmo Warm-up

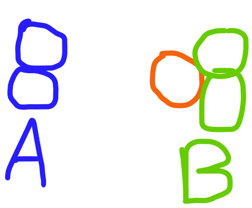
A **chemical reaction** causes the chemical compositions of substances to change. **Reactants** are substances that enter into a reaction, and **products** are substances produced by the reaction. The *Collision Theory* Gizmo allows you to experiment with several factors that affect the rate at which reactants are transformed into products in a chemical reaction.



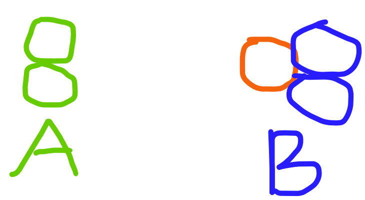
You will need blue, green, and orange markers or colored pencils for the first part of this activity.

1. Look at the key at the bottom of the SIMULATION pane. In the space below, draw the two reactants and two products of this chemical reaction.

Reactants:



Products:



2. Click **Play** (▶). What do you see?

Reactant A molecules are moving around in the space at some speed, and they are colliding with reactant B molecules which are vibrating (can be a solid). When the reactants collide at the right angle and speed, the bonds between them are broken and new bonds are formed. The products are based on these new bonds.

Activity A: **Temperature**	Get the Gizmo ready: • Click **Reset** ( ). • Check that the **Reactant concentration** is set to 1.0 mol/L, the **Catalyst concentration** is set to 0.00 mol/L, and the **Surface area** is **Minimum**.	

Question: How does temperature affect the rate of a chemical reaction?

1. Observe: Select the ANIMATION tab. View the animation with **No catalyst** selected.

   What do you see?

   Two molecules, each of a different reactant meet in a collision, combine for a short period of time, and then separate. When the separation occurs, the atoms in the reactant molecules are bonded to the atoms of the other reactant. The new molecules are the products of this reaction. Chemical bonds between the atoms are broken, and new bonds between other atoms are formed.

   When two reactant **molecules** meet, they form a temporary structure called an **activated complex**. The activated complex breaks up into the product molecules.

2. Observe: Return to the CONTROLS pane. Set the **Temperature** to 0 °C and the **Simulation speed** to its maximum setting. Click **Play**.

   Describe the motions of the molecules.

The reactant A molecules are moving around the space at some speed while the reactant B particles stay at one place and continuously vibrate. It is observed that while the reactant A molecules have collisions with reactant B molecules, most of the time, no new product is formed. The reaction process is extremely slow.

   A. Now set the **Temperature** to 200 °C. How does increasing the temperature affect the motions of the molecules?

   Increasing the temperature to 200 °C greatly increases the speed of the reactant molecules.

   B. What do you notice about the chemical reaction at the higher temperature?

At the higher temperature, it is observed that the chemical reaction takes place much faster because the reactant molecules collide with each other and form new product molecules at a faster rate.

3. Interpret: Select the GRAPH tab. Click the zoom out button (–) until you can see the whole graph. What does this graph show?

The graph shows the concentration of the reactants (mol/L) and products (mol/L) over time

(min).

4. Predict: How do you think temperature will affect the rate of a chemical reaction?

Increasing the temperature will increase the rate of a chemical reaction due to a higher frequency of collisions between the reactants and products. The molecules will also have more kinetic energy, increasing the chances of them reacting.

(Activity A continued on next page)

Activity A (continued from previous page)

5. Gather data: Click **Reset**. A useful way to compare reaction rates is to record the time required for half of the reactants to react, called the **half-life** of the reaction. With the **Temperature** set to 200 °C, click **Play**. Click **Pause** (⏸) when the number of reactant molecules is 10. Record the half-life time in the first space of the table below.

Time (min:sec)

Trial	200 °C	150 °C	100 °C	50 °C
1	6:14	8:58	30:56	75:20
2	6:32	10:48	15:17	67:38
Mean half-life (min:sec)	6:23	9:53	23:07	71:29

Repeat the experiment at different temperatures to complete the table. (Note: To get exact times, you can refer to the TABLE tab.)

6. Calculate: Calculate the mean half-life for each temperature. Fill in these values above.

   (Hint: To get an exact mean, first convert each time to seconds by multiplying the minutes value by 60 and adding this to the seconds. To find the mean in seconds, add up the two times and divide by two. Convert the answer back to minutes and seconds.)

7. Analyze: What do your results indicate?

The results indicate that half life increases as temperature decreases. The shortest half-life of 6 minutes and 23 seconds was at 200 °C. The longest half-life of 71 minutes and 29 seconds was at 50 °C.

8. Draw conclusions:

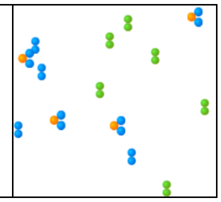
   For two molecules to react, they must collide at just the right angle and with enough energy to break the original bonds and form new ones. Based on these facts, why does the reaction tend to go more quickly at higher temperatures?

   At higher temperatures, the molecules are moving at higher speeds, which means they have more kinetic energy. The frequency of collisions also increases, and this results in more collisions. These extra collisions at higher energies helps the reaction occur faster as the bonds are broken more easily.

9. Apply: Paper must be heated to 234 °C to begin reacting with oxygen. This can be done by putting the paper over a flame. Why do you think the paper must be heated to start burning?

The paper must be heated to start burning because enough energy must be supplied to break bonds in the molecules of paper. The reactant particles move at faster speeds (more kinetic energy) and this results more frequent, high energy collisions. The paper then starts reacting with the oxygen.

<table>
<tr>
<td>Activity B:

Surface area and concentration</td>
<td><u>Get the Gizmo ready</u>:
• Click Reset.
• Check that the Catalyst concentration is set to 0.00 mol/L and the Surface area is Minimum.
• Set the Temperature to 200 °C.</td>
<td></td>
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Introduction: Reaction rates are also influenced by **surface area** and **concentration**. The surface area of a solid is a measure of how much of the solid is exposed to other substances. The concentration of a substance is a measure of how many molecules of that substance are present in a given volume.

Question: How do surface area and concentration affect reaction rates?

1. Observe: Change the **Surface area** from **Minimum** to **Maximum**. You can imagine that a solid reactant has been dissolved in a liquid.

   How does this change how many **Reactant B** molecules are exposed to **Reactant A**?

   This increases the number of Reactant B molecules are exposed to Reactant A as they are more dispersed. This increases the number of collisions that the Reactant B molecules experience.

2. Predict: How do you think increasing the surface area will affect the rate of the reaction?

   Increasing the surface area will increase the rate of the reaction because both reactants will have a higher chance of colliding with each other. More frequent collisions will result in a faster rate of reaction.

3. Gather data: Set the **Reactant concentration** to 2.0 mol/L. Use the Gizmo to measure the half-life of the reaction for each surface area setting. (There will now be 20 reactant molecules left at the half-life.) Then, calculate the mean half-life for each setting.

Time (min:sec)

Trial	Minimum surface area	Maximum surface area
1	4:28	0:54
2	3:46	0:56
Mean half-life (min:sec)	4:07	0:55

4. Analyze: What do your results indicate?

The results indicate that the half-life of the reaction reduces significantly when the surface area is increased. The rate of the reaction increases significantly.

5. Explain: Why does the reaction proceed more quickly when the surface area is increased?

When the surface area is increased, the molecules of Reactant A are more exposed to the molecules of Reactant B. There are also more possible angles for the molecules of Reactant B to collide with the molecules of Reactant A. This results in more frequent collisions between the reactants.

(Activity B continued on next page)

Activity B (continued from previous page)

6. Observe: Click **Reset**. Move the **Reactant concentration** slider back and forth. What do you notice?

   The number of reactant molecules increases or decreases. This increases or reduces the concentration of the reactants.

7. Predict: How will increasing the reactant concentration affect the rate of the reaction? Why?

   Increasing the reactant concentration will increase the rate of the reaction. There will be more molecules of the reactants colliding with each other resulting in a higher frequency of collisions. Higher frequency of collisions results in a higher rate of reaction.

8. Gather data: Make sure the **Temperature** is 200 °C and the **Surface area** is **Maximum**. Use the Gizmo to measure the half-life for each given reactant concentration. (Note that the number of reactant molecules changes with each concentration.) Calculate the means.

Time (min:sec)

Trial	0.4 mol/L	0.8 mol/L	1.2 mol/L	1.6 mol/L	2.0 mol/L
1	10:23	3:12	2:02	1:24	1:18
2	9:47	3:21	1:37	1:16	0:58
Mean half-life (min:sec)	10:05	3:17	1:50	1:20	1:08

9. Compare: If possible, find the mean times for each concentration for your entire class. What is the mean class time for a concentration of 0.4 mol/L? How about for 2.0 mol/L?

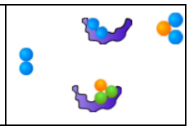
   Mean for 0.4 mol/L: 10:05 Mean for 2.0 mol/L: 1:08

10. Analyze: What do these results indicate?

These results indicate that the reaction time reduces as the concentration of the reactants increases. The reaction rate increases. The above prediction was true.

11. Apply: Hydrochloric acid reacts with the mineral calcite to produce carbon dioxide gas, water, and calcium chloride. Based on what you have learned in activity A and activity B, what are *three* things you could do to make the reaction occur more quickly?

    The three things that could be done to make the reaction occur more quickly would be to increase the temperature of the reactants, increase the surface area of the reactants, and increase the concentrations of the reactants. The higher temperatures will increase the speed of the molecules, which means more kinetic energy in the molecules. This results in more frequent and energetic collisions. The increase in surface area of the reactants will increase the probability of the particles colliding with each other, as well as increase the possible angles the molecules can collide with each other. The increased reactant concentration will result in more molecules colliding with each other in the same space. More frequent collisions will occur as there is less distance between reactant molecules. All of these factors together increase the rate of the reaction.

Activity C: **Catalysts**	Get the Gizmo ready: • Click **Reset** ( ).	

Introduction: A **catalyst** is a substance that helps a chemical reaction to proceed. The catalyst molecules are not changed by the reaction and can be reused over and over again.

Question: How do catalysts affect the rate of a chemical reaction?

1. Observe: Select the ANIMATION tab. Select **With catalyst**, and observe.

    A. What do you see?

    The reactant molecules move towards the catalyst and group together temporarily. They eventually separate as two new product molecules.

    B. Why do you think the shape of a catalyst is important?

    The shape of a catalyst is important because the reactant molecules can fit the shape of the catalyst and collide at a specific angle. This allows them to react easily.

Many catalysts have a special shape that allows them to bind to specific reactant molecules.

2. Predict: How do you think catalysts will affect the rate of a chemical reaction?

The catalysts will increase the rate of a chemical reaction because they group together the reactant molecules allowing them to react more quickly. I also think that the energy required for the reaction to occur would be less.

3. Gather data: On the CONTROLS pane, set the **Reactant concentration** to 2.0 mol/L, the **Surface area** to **Maximum**, and the **Temperature** to 50 °C. Measure the half-life for each given catalyst concentration. Calculate the means.

Trial	**Catalyst concentration**			
	0.00 mol/L	**0.05 mol/L**	**0.10 mol/L**	**0.15 mol/L**
1	23:52	6:32	2:28	1:30
2	29:37	4:44	3:06	1:37
Mean half-life	26:55	5:38	2:47	1:34

4. Analyze: What do your results indicate?

The results indicate that as the concentration of the catalyst increases, the half-life of the reaction decreases. This means that the reaction rate increases. The prediction above was correct.

(Activity C continued on next page)

Activity C (continued from previous page)

5. Explore: Set the **Catalyst concentration** to 0.00 mol/L and the **Temperature** to 0 °C. Click **Play**, wait for 10 minutes of simulated time, and click **Pause**.

    A. What happens?

The reaction is extremely slow. There were 38 reactant molecules left, and two product molecules formed.

    B. Click **Reset**, set the **Catalyst concentration** to 0.25 mol/L, and click **Play**. After 10 simulated minutes, click **Pause**. What happens now?

The reaction was fully complete before the simulated time reached 10 minutes.

    C. Why do you think the catalysts allowed the chemical reaction to take place at 0 °C?

The reactants were able to bind with the catalyst which had the correct shape. After the reactants were grouped together by the catalysts, the reaction between the two molecules occurred and two product molecules were formed. It seems as if the energy required for the reaction to occur was reduced by the presence of the catalyst.

6. Draw conclusions: What is the usefulness of catalysts?

The catalysts speed up the rate of a reaction. They are especially useful in situations where the conditions are less favorable for the reaction to take place. These conditions include low temperatures, low concentrations, and low surface area. Without the catalysts, the reaction would be extremely slow (in the less favorable conditions).

7. Apply: Most of the chemical reactions inside your body rely on protein catalysts called **enzymes** to take place. For example, the enzyme pepsin helps to break down protein molecules in your stomach. What might happen if your stomach stopped producing pepsin?

If your stomach stopped producing pepsin, the body would have a hard time breaking down protein molecules. It may not even be able to break them down at all without pepsin. If the body does not break down the protein due to the lack of pepsin production, the body would not be able to absorb any protein that is consumed. Protein is extremely important for building and maintaining tissue and muscles in your body. It also has many other functions in the body. Without protein, there would be many health problems that will occur.