Lesson Plan

EQUILIBRIUM

Time

Approximately 90-120 minutes

Lesson Description

In this lesson, students will use Collisions to explore Le Châtelier's Principle and determine how the Haber Process should be modified in order to increase the number of products.

Key Essential Questions

1. How do changes in the concentration of reactants and products of a reversible reaction affect its equilibrium?
2. How do changes in the temperature of a reversible reaction affect its equilibrium?
3. How do changes in the partial pressures of a reversible reaction affect its equilibrium?

Learning Outcomes

Students will be able to determine how temperature, pressure, and concentration can be manipulated to modify the equilibrium position of a reaction.

Prior Student Knowledge Expected

- Components of a chemical equation (coefficients, yield arrow, state symbols, etc.)
- Endothermic & exothermic reactions

Lesson Materials

- Individual student access to Collisions on tablet, Chromebook, or computer.
- Projector / display of teacher screen
- Accompanying student resources (attached)

STANDARDS ALIGNMENT

<table>
<tr><th colspan="3">NGSS Alignment</th></tr>
<tr><td colspan="3">HS PS1-6: Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.</td></tr>
<tr><td colspan="3">[Clarification Statement: Emphasis is on the application of Le Châtelier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.] [Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.]</td></tr>
<tr><td>Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

• Refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-PS1-6)</td><td>PS1.B: Chemical Reactions
• In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present. (HS-PS1-6)

ETS1.C: Optimizing the Design Solution
• Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (secondary to HS-PS1-6)</td><td>Stability and Change
• Much of science deals with constructing explanations of how things change and how they remain stable. (HS-PS1-6)</td></tr>
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PART 1: ENGAGE

Warm-Up (5 minutes)

Present students with the following prompt either by writing it on the board, projecting it, etc. and have them reflect and answer them independently:

Imagine one dry, hot summer day that your parent or guardian came into your room and saw that you had a large pile of dirty clothes. They demand that you have them washed and put away by the time they get back from work. You spend most of your day binge watching TV and finally decide to wash the clothes only a few hours before your parent/guardian gets home. You walk down to the cool, damp basement and load the clothes into the washer. When you return to move them to the dryer, however, you discover that the dryer is not working.

What will you do to get your clothes dried quickly before your parent/guardian returns home? Explain your reasoning by describing your process at the ***molecular*** *level.*

Discuss (5 minutes)

Students should share their answers with the class. Expect most students to say that they would hang them outside to dry.

Then present the equation **H_2O (liquid) + Energy ⇋ H_2O (gas)** and push students to use it to explain that the sunlight and higher **temperature** outside as compared to a cool basement will cause evaporation to happen more readily as water molecules gain more energy to escape the intermolecular forces of the liquid phase (remind students of what they learned in the Phase Change game).

Use the same equation **H_2O (liquid) + Energy ⇋ H_2O (gas)** to stretch things even further by asking why even if the basement were the same temperature as outside and it were nighttime, you would still want to put the clothes outside. Have students start connecting the idea that the air outside is both drier (according to the prompt) and likely moving (breezy), whereas the basement is damp and humid. The water that just evaporated will be carried away allowing more water in the clothes to evaporate. The **concentration** of water in the air surrounding the clothes is lower outside than inside.

Phenomenon Introduction (5 minutes)

Present the following to students:

Processes are generally affected by the conditions at which they happen, just like the process of drying the clothes in the cool, damp basement versus instead of out on the clothes line in the dry heat. In that scenario, you took advantage of temperature and the concentration of water vapor in the air (humidity) to get the clothes to dry faster. There are, however, huge challenges that humans have addressed by taking advantage of temperature, concentration, and pressure. One could argue it has been used in one of the most important innovations in human history.

Introduce the Bosch Process and the equation **N_2 + 3H_2 ⇋ 2NH_3**. It is recommended that you show your students this engaging video[1] by TED-Ed from the start until around **2:04**. This will provide context for the phenomenon without giving away the details of the process. After showing the video, conclude your introduction with the following statement:

The goal of this lesson is to determine how engineers and scientists manipulate temperature, concentration, and pressure to maximize production of ammonia in the Haber Process.

[1]The Chemical Reaction That Feeds the World | Daniel D. Dulek | https://youtu.be/o1_D4FscMnU | For more TED-Ed, visit ed.ted.com

PART 2: EXPLORE

This is an inquiry-driven activity where students will use different levels of the Equilibrium game to help them test hypotheses about Le Châtelier's Principle and the Haber Process. A Student Worksheet for this activity can be found on pages 5-11. Direct students to log into Collisions with their individual username and password, enter the Equilibrium game, and follow the directions on the Student Worksheet on pages 5-6. Before students begin to arrive at Task 5, it might be useful to show them how to use the Sandbox. If you need help with the Sandbox, please refer to the Equilibrium Game Guide for help.

PART 3: EXPLAIN

Review the answers below with your students. After reviewing the answers to the exploration activity, it may be beneficial to students to receive some direct instruction in the format of your preference regarding Le Châtelier's Principle.

PART 4: ELABORATE

To stretch your students' comprehension of the Haber Process and the implications of trying to maintain a favorable equilibrium for the reaction, you can assign them this article and accompanying comprehension questions either during class or as homework. Students will take a look at the relationship between the Haber Process and climate change, as well as learn about research involving the Haber Process.

PART 5: EVALUATE

Assign students the Exit Ticket found on page 12. They will use Le Châtelier's Principle to be part of a chemical engineering team deciding how to adjust their Haber process reaction chamber to produce the most ammonia.

STUDENT EXPLORATION WORKSHEET

Directions

1. Complete your hypothesis for each scenario listed on the worksheet regarding the Haber Process.
2. Log into Collisions and enter the Equilibrium game.
3. Play the levels specified for each section of the worksheet below.

Concentration

Task 1: Determine how changes in concentration affect equilibrium by playing levels **1-5** of the Equilibrium game. While you are completing the game, fill out the table below to keep track of your experiences by simply explaining how you shifted each reaction to the right or the left (e.g. "Decrease the concentration of N_2"). Once finished with the levels, fill in the blanks of the statements at the end.

Level(s)	Reaction	How do you shift the reaction to the left?	How do you shift the reaction to the right?
1 & 2	$H_2\,(g) + I_2\,(g) \leftrightharpoons 2\,HI\,(g)$		
3	$CO\,(g) + H_2O\,(g) \leftrightharpoons 2\,CO_2\,(g) + H_2\,(g)$		
4	$H_2\,(g) + Cl_2\,(g) \leftrightharpoons 2\,HCl\,(g)$		
5	$CO\,(g) + H_2O\,(g) \leftrightharpoons 2\,CO_2\,(g) + H_2\,(g)$		

Using what you have learned, complete the statements below:

- Increasing the concentration of reactants will drive the reaction to the _____(**right or left**), but increasing the concentration of products will drive the reaction to the _____(**right or left**).

- Decreasing the concentration of reactants will drive the reaction to the _____(**right or left**), but decreasing the concentration of products will drive the reaction to the _____(**right or left**).

Task 2: Use what you learned from the levels you just played to predict what will happen as a result of concentration changes in the Haber Process. The chemical equation has been provided. For each claim that you make, **be sure to support your claim with evidence from the game and explanation of your reasoning for why that evidence supports your claim.**

Haber Process: $N_2 + 3H_2 \leftrightharpoons 2NH_3 + Heat$ Nitrogen + Hydrogen ⇋ Ammonia		
Claim	**Evidence**	**Reasoning**
If the concentrations of **N_2** or **H_2** are increased, then _____ (more/less) **NH_3** will be produced.		
If the concentrations of **N_2** or **H_2** are decreased, then _____ (more/less) **NH_3** will be produced.		
If the concentration of **NH_3** is increased, then _____ (more/less) **N_2** and **H_2** will be produced.		
If the concentration of **NH_3** is decreased, then _____ (more/less) **N_2** and **H_2** will be produced.		

Temperature

Task 3: Continue to play through the levels to unlock Level 8. You will then determine how changes in temperature affect equilibrium by playing levels **8-10** of the Equilibrium game. While you are completing the game, fill out the table below to keep track of your experiences by determining if the reaction is endothermic or exothermic and then explaining how you shifted each reaction to the right or the left (e.g. "Increase the temperature"). Once finished with the levels, fill in the blanks of the statements at the end.

Level(s)	Reaction	Endothermic or Exothermic?	How do you shift the reaction to the left?	How do you shift the reaction to the right?
8	$CuCl\ (s) + Heat \rightleftharpoons Cu^{+}\ (aq) + Cl^{-}\ (aq)$			
9	$AgCl\ (s) + Heat \rightleftharpoons Ag^{+}\ (aq) + Cl^{-}\ (aq)$			
10	$CO\ (g) + H_2O\ (g) \rightleftharpoons CO_2\ (g) + H_2\ (g) + Heat$			

Using what you have learned, complete the statements below:

- Increasing the temperature of an endothermic reaction will drive it to the _____(**right** or **left**) because heat can be thought of as a _____ (**reactant** or **product**).
- Decreasing the temperature of an endothermic reaction will drive it to the _____(**right** or **left**) because heat can be thought of as a _____ (**reactant** or **product**).
- Increasing the temperature of an exothermic reaction will drive it to the _____(**right** or **left**) because heat can be thought of as a _____ (**reactant** or **product**).
- Decreasing the temperature of an exothermic reaction will drive it to the _____(**right** or **left**) because heat can be thought of as a _____ (**reactant** or **product**).

Task 4: Use what you learned from the levels you just played to predict what will happen as a result of temperature changes in the Haber Process. The chemical equation has been provided. For each claim that you make, **be sure to support your claim with evidence from the game and explanation of your reasoning for why that evidence supports your claim.**

Haber Process: $N_2 + 3H_2 \leftrightharpoons 2NH_3 + Heat$ Nitrogen + Hydrogen ⇋ Ammonia		
Claim	**Evidence**	**Reasoning**
If the temperature of the reaction is increased, then _____ (more/less) **NH_3** will be produced.		
If the temperature of the reaction is decreased, then _____ (more/less) **NH_3** will be produced.		

Pressure

Task 5: Determine how changes in pressure affect equilibrium by playing levels **11** and **12** of the Equilibrium game. After you finish level **12**, enter the sandbox and use the reactions identified in the table below to determine how changes in pressure affect them. While you are completing levels **11,12**, and the sandbox reactions, fill out the table below to keep track of your experiences. Determine which side has more moles of gas (by adding the coefficients for all gaseous reactants) and then explaining how you shifted each reaction to the right or the left (e.g. "Increased the pressures of the gases"). Once finished with the levels, fill in the blanks of the statements at the end.

Levels	Claim	Moles of Gaseous Reactant	Moles of Gaseous Product	How did you shift the reaction to the left by changing the pressure?	How did you shift the reaction to the right by changing the pressure?
11	$2SO_3\,(g) + \text{Heat} \leftrightharpoons 2SO_2\,(g) + O_2\,(g)$				
12	$2NO_2\,(g) + \text{Heat} \leftrightharpoons 2NO\,(g) + O_2\,(g)$				
Sandbox	$CO\,(g) + 3H_2\,(g) \leftrightharpoons CH_4\,(g) + H_2O\,(g) + \text{Heat}$				
Sandbox	$2CO\,(g) + O_2\,(g) \leftrightharpoons 2CO_2\,(g) + \text{Heat}$				
Sandbox	$CO\,(g) + H_2O\,(g) \leftrightharpoons CO_2\,(g) + H_2\,(g) + \text{Heat}$				

Using what you have learned, complete the statements below:

- Increasing the pressures of all gases in a reaction will drive it to the side that has _____ (**more or fewer**) moles of gas.
- Decreasing the pressures of all gases in a reaction will drive it to the side that has _____ (**more or fewer**) moles of gas.
- When the number of moles of gases is the same on both sides, increasing or decreasing the pressures of all gases has _____ (**no or some**) effect on the equilibrium.

Task 6: Predict what will happen as a result of pressure changes in the Haber Process.

Haber Process: $N_2 + 3H_2 \leftrightharpoons 2NH_3 + Heat$ Nitrogen + Hydrogen $\leftrightharpoons$ Ammonia		
Claim	**Evidence**	**Reasoning**
If the pressures of the substances is increased, then _____ (more/less) **NH_3** will be produced.		
If the pressures of the substances is decreased, then _____ (more/less) **NH_3** will be produced.		

Task 7: Navigate back to the levels screen of the Equilibrium Game and enter the Sandbox.

- In the **"Your Initial Claim"** column of the table below, complete each of your original claims. You will now be able to test each claim you made about the Haber Process by selecting the reaction **N_2 + 3H_2 ⇋ 2NH_3 + Heat** in the sandbox and initiating the necessary change in temperature, concentration, or pressure.
- In the **"Supported by Test?"** column, state if your initial claim was supported or not supported by the results of your test by writing "Yes" or "No".
- In the **Explanation** column, explain how the results of your test either supported or did not support your initial claim by simply describing what happened in each test.

Your Initial Claim	Supported by Test?	Explanation
If the concentrations of **N_2** or **H_2** are increased, then_____ (more/less) **NH_3** will be produced.		
If the concentrations of **N_2** or **H_2** are decreased, then _____ (more/less) **NH_3** will be produced.		
If the concentration of **NH_3** is increased, then _____ (more/less) **N_2** or **H_2** will be produced.		
If the concentration of **NH_3** is decreased, then _____ (more/less) **N_2** or **H_2** will be produced.		
If the temperature of the reaction is increased, then _____ (more/less) **NH_3** will be produced.		
If the temperature of the reaction is decreased, then _____ (more/less) **NH_3** will be produced.		
If the pressures of the substances are increased, then _____ (more/less) **NH_3** will be produced.		
If the pressures of the substances is decreased, then _____ (more/less) **NH_3** will be produced.		

EXIT TICKET

The chemical engineering team for a fertilizer manufacturing company has been attempting to improve the amount of ammonia produced at their plant. While in a brainstorming session, they covered a whiteboard with statements shouted out by team members regarding the pros and cons of three different strategies under consideration. The statements appear all over the whiteboard with no organization and little context. You have been given the task of "note taker" and asked to organize the statements written on the whiteboard into the template provided. Use your understanding of Le Châtelier's Principle and the background information provided to determine where each statement should be written and then answer the question at the end. Some boxes will have more than one statement.

Background Information: The Haber Process **($N_2 + 3H_2 \rightleftharpoons 2NH_3 + Heat$)** is used to generate large quantities of ammonia for many purposes, including chemical fertilizer. As you have seen, temperature, pressure, and concentration can be manipulated in order to improve the amount of ammonia produced by the Haber Process. However, the catch is that without very high temperatures, the process would be far too slow. As such, the reaction is often performed at around 400-450°C.

Brainstorming Whiteboard

The reaction will shift to the left due to the change in pressure.	The reaction rate will increase.	The reaction will shift to the left due to the change in temperature.	Reaction will become too slow.
Increased cooling costs.	Reduced pressurization costs.	Reaction will shift to the right due to the change in temperature.	Reaction will shift to the right due to the change in concentration.
Most likely to present issues the team has not experienced before.			

Notes

Strategy	**Pros**	**Cons**
The temperature of the reaction will be increased. At the same time, the pressures of the substances will be decreased.		
The reaction will be continuously cooled to a temperature of 25°C.		
Ammonia will be removed from the reaction chamber as it is produced in the reaction chamber using a newly developed process that allows the temperature and pressure to stay high.		

Which of these strategies should be performed and why?