EQUILIBRIUM and LE CHATELIER'S PRINCIPLE

Why?

When opposing forces or issues are balanced, a system is said to be in equilibrium. Equilibrium in chemical reactions is dynamic because the forward and reverse reactions are occurring continuously and simultaneously at the same rates. Placing a stress on any equilibrium system, whether it is chemical, biological, societal, environmental, or personal, causes the equilibrium position to change. Le Chatelier's Principle allows us to predict the results that follow from changing the conditions of a system at chemical equilibrium. This allows scientists to develop techniques to control chemical reactions in natural and industrial settings in order to obtain desired products.

LEARNING OBJECTIVES

- Be able to explain the concept of chemical equilibrium.
- Identify factors that disrupt a system that is at chemical equilibrium.
- Determine the direction of the shift in the equilibrium that relieves a stress.
- Determine the effect of a shift in the equilibrium on the initial and final concentrations of the reactants and products in a chemical reaction.

CONCEPTS

- Equilibrium
- Endothermic /Exothermic Reactions
- Equilibrium stresses
- Le Chatelier's Principle

PREREQUISITES

- Reaction equations
- Energy in reactions
- Reaction Kinetics

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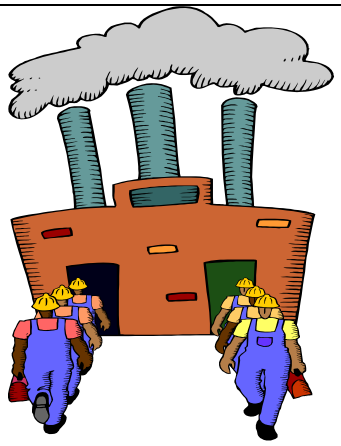
MODEL 1: Dynamic Equilibrium



Acme Manufacturing has been restricted to 100 employees in the building at one time. Throughout the day, twenty employees go on break each hour as twenty other employees return from break.

Chemical Equilibrium

$$2H_2\,(g) + O_2\,(g) \leftrightarrow 2H_2O\,(g) + \text{energy (heat)}$$

Questions

1. How many employees move in and out of the factory building during each hour?

2. Are the employees who move in and out of the building each hour the same people? Explain your answer.

3. Does the number of employees in the building change from hour to hour? Explain your answer.

4. Over the course of a day, the employees in the Acme Manufacturing Plant are said to be in a "dynamic equilibrium", Based on your understanding of how the staff move in and out of the plant, explain what is meant by the term "dynamic equilibrium".

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5. A new faster and simpler check-in/check-out process has been proposed for workers at the Acme Manufacturing Plant. Some workers have said that this new process acts like a catalyst. (A catalyst is a substance that speeds up a chemical reaction without changing the outcome of the reaction and without being used up in the process.)
    a. Would this new check-in/check-out process change the number of people in the building at any given time? Why or why not?

    b. What would be the effect of the new check-in/check-out process on the workers at the factory?

    c. Support or refute the idea that the new check-in/check-out process is like a catalyst.

Like the Acme Manufacturing Plant, chemical reactions can also reach equilibrium. Answer the following questions about the chemical equation in Model 1 by applying the insight you gained from the Acme Manufacturing Plant questions.

6. When the reaction between hydrogen and oxygen **reaches equilibrium**:
    a. Does the number of molecules in the reaction vessel change? Explain.

    b. Is the reaction still proceeding in the forward direction?

    c. Is the reaction still proceeding in the reverse direction?

    d. Are the concentrations of the products and reactants changing?

    e. Are the rates of the forward and reverse reactions the same?

    f. Does the heat content of the system become constant?

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MODEL 2: LE CHATELIER'S PRINCIPLE

Reactant: Increase (↑) causes the equilibrium to shift to the right (→)
Decrease (↓) causes the equilibrium to shift to the left (←)

Product: Increase (↑) causes the equilibrium to shift to the left (←)
Decrease (↓) causes the equilibrium to shift to the right (→)

Temperature: A change in temperature corresponds to a change in energy therefore by using the 'energy' term in the equation itself, it can be treated like a reactant or product (see above).

Pressure: An increase (↑) in pressure causes the equilibrium to shift towards the "smaller number of moles *of gas"* side.
A decrease (↓) in pressure causes the equilibrium to shift towards the "larger number of moles *of gas"* side.
Note: If the number of moles of gas is the same on both sides, then a change in pressure has no effect in the equilibrium.

The following equation describes a system that is at equilibrium:

$$2H_2\,(g) + O_2\,(g) \leftrightarrow 2H_2O\,(g) + \text{energy (heat)}$$

In Table 1 apply Le Chatelier's Principle and indicate the direction of the shift in equilibrium if the indicated stress is applied to the reaction system. (The first one is completed for you.)

Key Questions

1. Complete the following table:

Stress	Shift Direction
Concentration H_2 increases	→ shifts to the right
Concentration H_2 decreases	
Concentration of O_2 increases	
Concentration of O_2 decreases	
Concentration of H_2O increases	
Concentration of H_2O decreases	
Temperature increases	
Temperature decreases	
Pressure increases	
Pressure decreases	

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The following questions are based on the table in Question #1

2. In general terms, describe the direction of the equilibrium shift when the concentration of a reactant is increased.

3. If an equilibrium shifts to the right, which reaction speeds up, the forward or the reverse?

4. What happens to the concentrations of the reactants H_2 and O_2 when the reaction in Model 2 shifts to the right?

5. What happens to the concentration of the product H_2O when the reaction in Model 2 shifts to the right?

6. If an equilibrium shifts to the left, which reaction speeds up, the forward or the reverse?

7. What happens to the concentrations of the reactants H_2 and O_2 when the reaction in Model 2 shifts to the left?

8. What happens to the concentration of the product H_2O when the reaction in Model 2 shifts to the left?

9. What is true of the reaction rates for the forward and reverse reactions when a new equilibrium is established?

Got It!

Write a general description based on the information in Table 1 that describes what happens to an equilibrium system when conditions change.

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EXERCISES:

1. Fill in the blanks in the chart below, given the reaction to form nitrogen oxide in a container.

$$N_2\,(g) + O_2\,(g) \quad + \text{ heat } \Leftrightarrow 2\,NO\,(g)$$

	Stress	**Shift** (right/left)	**Amount** (increases/decreases)
1.	N_2 added		of NO
2.	O_2 removed		of N_2
3.	NO removed		of N_2
4.	Heat added		of NO

PROBLEMS:

The production of ammonia gas from its gaseous elements (with the release of heat) is a common industrial reaction known as the Haber Process. In order to maximize the yield of ammonia gas in the shortest amount of time, Le Chatelier's Principle is used to guide the conditions used by manufacturers when making ammonia.

1. Write the complete balanced chemical reaction for the Haber Process (include heat in the reaction equation.)

2. Create a chart similar to Table 1 that lists the possible stresses, the resulting direction of equilibrium shift, and the impact on the chemical concentrations of the reactants and products for this reaction.

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3. Based on the balanced equation and information in your chart, describe the conditions that would produce the highest yield of NH_3 (g) in the shortest amount of time.

4. Research: Under what conditions does the Haber Process actually run? If the conditions are different from the conditions in you described in Problem # 3, explain why?

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