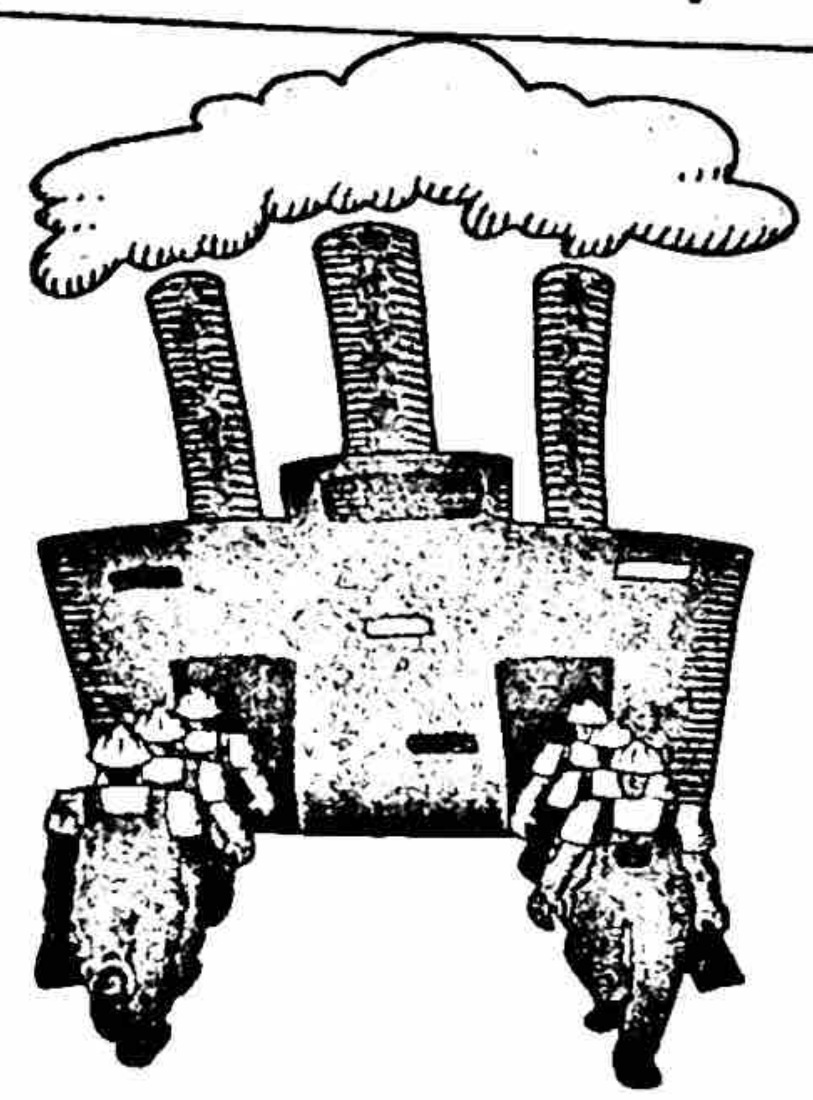
MODEL 1: *Dynamic Equilibrium*



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?

   40 employees

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

   NO, different employees come in and out

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

   NO, it will always have 100 employees inside

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".

   the same # of employees are moving in and out but the number of employees inside and outside the plant stays the same

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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?

      No, just increases the speed that the exchange can occur

   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.

$2H_{2(g)} + O_{2(g)} \rightleftharpoons 2H_2O_{(g)}$ + energy (heat)

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

      NO

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

      yes

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

      yes

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

      NO

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

      yes

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

      yes

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MODEL 2: LE CHATELIER'S PRINCIPLE

know this

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:

3 2

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

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.

   Shift to the right

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

   forward

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

   decreases

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

   increases

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

   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?

   increases

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

   decreases

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

   they are equal

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	right	of NO increases
2.	O_2 removed	left	of N_2 increases
3.	NO removed	right	of N_2 decrease
4.	Heat added	right	of NO increases

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.)

$$N_2 + 3H_2 \rightarrow 2NH_3 + \text{heat}$$

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.

↓ [NH_3] ↓ heat

↑ [N_2] + [H_2] ↑ pressure

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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LeChatelier's Principle

1. What is Le Chatelier's Principle?
how a reaction responds to a stress put on it to get back to equilibrium

Complete the following charts by writing →, ←, or none for "shift" & increase, decrease or stay the same for the concentrations of reactants and products.

Reaction: $N_2(g) + 3H_2(g) \leftrightarrow 2NH_3(g) + 100.4\ kJ$

Stress	Equilibrium Shift	[nitrogen]	[hydrogen]	[Ammonia]
Add nitrogen	→	↓	↓	↑
Add hydrogen	→	↓	↓	↑
Add ammonia	←	↑	↑	↓
Remove nitrogen	←	↑	↑	↓
Remove hydrogen	←	↑	↑	↓
Remove ammonia	→	↓	↓	↑
Increase temperature	←	↑	↑	↓
Decrease temperature	→	↓	↓	↑
Increase pressure	→	↓	↓	↑
Decrease pressure	←	↑	↑	↓
Add catalyst	N/A	N/A	N/A	N/A

Reaction: $NaOH(s) \leftrightarrow Na^+(aq) + OH^-(aq) + 10.6\ kJ$ **remember pure (s) & (l) do not affect equilibrium values**

Stress	Equilibrium Shift	Amount NaOH (s)	$[Na^+]$	$[OH^-]$	K
Add NaOH (s)	N/A	↑	N/A	N/A	N/A
Add NaCl (adds Na ions)	←	↑	↓	↓	N/A
Add KOH (adds OH ions)	←	↑	↓	↓	N/A
Increase temperature	←	↑	↓	↓	↓
Decrease temperature	→	↓	↑	↑	↑
Increase P	N/A	N/A	N/A	N/A	N/A
Decrease P	N/A	N/A	N/A	N/A	N/A

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Name ______________________ Period ______
Date ______________________

EQUILIBRIUM "SHIFTS"

Indicate what happens to the equilibrium position when the indicated stress or condition change occurs. (Shift left, shift right, or no change)

1. $N_{2(g)} + 3H_{2(g)} \leftrightarrow 2NH_{3(g)}$ + energy
   a) remove NH_3 gas →
   b) decrease pressure ←

2. $2SO_{2(g)} + O_{2(g)} \leftrightarrow 2SO_{3(g)}$ + energy
   a) increase temperature ←
   b) increase $[SO_2]$ →

3. $CO_{2(g)} + C_{(s)}$ + energy $\leftrightarrow 2CO_{(g)}$
   a) increase temperature →
   b) increase [CO] ←

4. $H_{2(g)} + Cl_{2(g)} \leftrightarrow 2HCl_{(g)}$ + energy
   a) increase pressure no change
   b) increase H_2 concentration →

5. $N_2O_{4(g)}$ + energy $\leftrightarrow 2NO_{2(g)}$
   a) decrease pressure (N_2O_4 and NO_2 are both gases) →
   b) remove N_2O_4 ←

Answer the following.

6. What is the equilibrium expression for the following reaction?

$$CO_{2(g)} + C_{(s)} \leftrightarrow 2CO_{(g)}$$

$$Keq = \frac{[CO]^2}{[CO_2]}$$

7. What is the equilibrium expression for the following reaction?

$$2KClO_{3(s)} \leftrightarrow 2KCl_{(s)} + 3O_{2(g)}$$

$$Keq = [O_2]^3$$

8. What is the K_{eq} value for the following reaction at equilibrium at a temperature of 298 K if the concentrations (in mol/L) of the reactants and products are $[N_2O_4]$ = 0.0450 M and $[NO_2]$ = 0.0161 M? N_2O_4 (g) $\leftrightarrow$ $2NO_2$(g)

$$Keq = \frac{[NO_2]^2}{[N_2O_4]} = \frac{[0.0161]^2}{[0.0450]} = 0.00576$$

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Equilibrium Expressions

1. Calculate the equilibrium concentration of HI for the reaction: $2HI = H_2 + I_2$ if Keq = 0.0186 and if the equilibrium concentrations are $[H_2] = 0.00290$ and $[I_2] = 0.0017$ (Ans: 0.0163 M)

$Keq = \frac{[H_2][I_2]}{[HI]^2}$

$0.0186 = \frac{(0.00290)(0.0017)}{x^2}$

$\frac{0.0186x^2}{0.0186} = \frac{4.93 \times 10^{-6}}{0.0186}$

$\sqrt{x^2} = \sqrt{2.65 \times 10^{-4}}$

$x = 0.016$ M

2. Calculate the equilibrium concentrations at 400°C of NH_3 for the reaction: $N_2 + 3H_2 = 2NH_3$. The equilibrium concentrations for the reactants at 400°C are $[N_2] = 0.45$ M and $[H_2] = 1.10$ M. The Keq at this temperature is 0.0017. (Ans: $[NH_3] = 0.032$M)

$Keq = \frac{[NH_3]^2}{[N_2][H_2]^3} \rightarrow 0.0017 = \frac{x^2}{(0.45)(1.10)^3}$

$\sqrt{x^2} = \sqrt{0.00102}$

$x = 0.032$ M

3. For the following equilibrium reaction: $N_2O_4 = 2NO_2$, a 3 liter flask at equilibrium is found to contain 10.8 moles of N_2O_4 and 5.25 moles of NO_2. Calculate Keq. (Ans: Keq = 0.85)

$M = \frac{mol}{L}$

$M = \frac{10.8 mol}{3L} = 3.6$ M N_2O_4

$M = \frac{5.25}{3L} = 1.75$ M NO_2

$Keq = \frac{[NO_2]^2}{[N_2O_4]}$

$Keq = \frac{[1.75]^2}{[3.6]} = 0.85 \rightarrow 0.9$

4. At a given temperature, the K_{eq} for the reaction $2HI(g) \rightarrow H_2(g) + I_2(g)$ is 1.40×10^{-2}. If the concentration of both H_2 and I_2 at equilibrium are 2.00×10^{-4}M, find the concentration of HI. (Ans: 0.00169M)

$Keq = \frac{[H_2][I_2]}{[HI]^2} \rightarrow 1.40 \times 10^{-2} = \frac{(2.00 \times 10^{-4})(2.00 \times 10^{-4})}{x^2}$

$1.40 \times 10^{-2} x^2 = 4.00 \times 10^{-8}$

$\sqrt{x^2} = \sqrt{2.86 \times 10^{-6}}$

$x = 0.00169$ M

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5. Acetic acid dissociates in water. If $K_{eq} = 1.80 \times 10^{-5}$ and the equilibrium concentrations of acetic acid is 0.09986M, what is the concentration of $H^+(aq)$ and $C_2H_3O_2^-(aq)$?

(Ans:0.00134M)

$HC_2H_3O_2(aq) \rightarrow H^+(aq) + C_2H_3O_2^-(aq)$ *since they are in a one to one ratio, we can assume their concentrations are equal *

$$K_{eq} = \frac{[H^+][C_2H_3O_2^-]}{[HC_2H_3O_2]} \rightarrow 1.80 \times 10^{-5} = \frac{[x][x]}{0.09986}$$

$$\sqrt{x^2} = \sqrt{1.797 \times 10^{-6}}$$

$$x = 0.00134\ M$$

6. At 60.2°C the equilibrium constant for the reaction $N_2O_4(g) \rightarrow 2NO_2(g)$ is 8.75×10^{-2}. At equilibrium at this temperature a vessel contains N_2O_4 at a concentration of 1.72×10^{-2}M. What concentration of NO_2 does it contain?

(Ans: 0.0388M)

$$K_{eq} = \frac{[NO_2]^2}{[N_2O_4]} \rightarrow 8.75 \times 10^{-2} = \frac{x^2}{1.72 \times 10^{-2}}$$

$$\sqrt{x^2} = \sqrt{0.001505}$$

$$x = 0.0388\ M$$

7. At equilibrium, K for the decomposition of HI(g) was found to be 1.07×10^{-5}. The equilibrium concentration of HI(g) was found to be 0.129M. Calculate the concentration of I_2 at equilibrium.
(Hint - Let x = the concentration of I_2. What would the concentration of H_2 be if x is the concentration of I_2? Refer to the coefficients of the equation to help you.) (same as #5)

$2HI(g) \rightarrow H_2(g) + I_2(g)$

(Ans: 0.000422M)

$$K_{eq} = \frac{[H_2][I_2]}{[HI]^2} \rightarrow 1.07 \times 10^{-5} = \frac{[x][x]}{(0.129\ M)^2}$$

$$\sqrt{x^2} = \sqrt{1.781 \times 10^{-7}}$$

$$x = 4.22 \times 10^{-4}\ M$$