EXPERIMENT 0

Reaction Rates & Chemical Equilibrium

A. Goal

The goal of this laboratory experiment is to identify the factors that impact the rate of a chemical reaction such as temperature, the presence of a catalyst, while testing Le Chatelier's principle.

B. Materials

- ☐ 0.1, 2M, and 3M HCl
- ☐ 400mL beaker
- ☐ ice
- ☐ thermometer
- ☐ $NaHCO_3$
- ☐ Mg
- ☐ 3% H_2O_2
- ☐ MnO_2, Zn, fresh and boiled potato
- ☐ 0.01M $Fe(NO_3)_3$ and 0.01M KSCN
- ☐ 1M $Fe(NO_3)_3$

C. Background

Le Chatelier principle

At this point, we have covered the idea of equilibrium and we have seen that the forward and reverse reactions have the same rate at equilibrium. Now, what happens if you alter this equilibrium? Le Châtelier principle claims a reaction will go back to its original equilibrium state by shifting left or right.

Le Chatelier principle

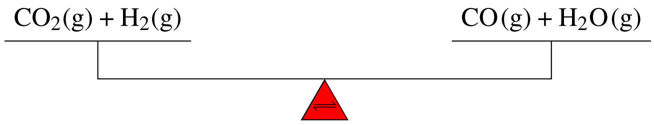
When a reaction is in equilibrium the forward and reverse reactions proceed at the same speed. Also in an equilibrium state, the concentrations of reactants and products have very specific values. Imagine that you create stress conditions by adding reactants or products or even changing the temperature. This stress will have an impact on the equilibrium and the reaction eventually will reach a new state of equilibrium by somehow counteracting this stress. Le Châtelier principle says that when stress is placed in a reaction (adding or removing reactant or products, increasing or decreasing temperature) the equilibrium will be shifted in the direction that relieves that stress. Table **??** displays different aspects regarding Le Châtelier's principle in terms of parameter change and consequence.

Change in concentration

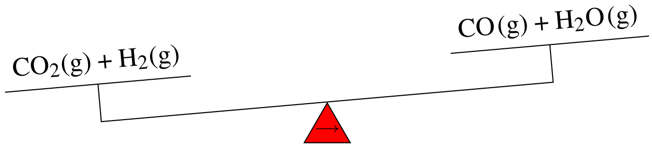
Let us consider the following equilibrium:

$$\mathrm{CO_2(g) + H_2(g) \rightleftharpoons CO(g) + H_2O(g)}$$

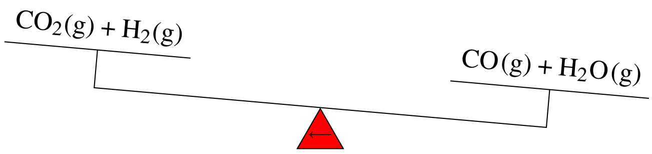
K_c for this reaction equals one at 1200K. This means that the concentration of reactants and products are the same. We can represent this using this balance or seesaw



If we add some CO_2 the equilibrium will be affected. To counteract this stress, the reaction will restore the equilibrium by decreasing the amount of CO_2. This can only be achieved by displacing the equilibrium to the right so that CO_2 is removed. Mind that CO_2 is consumed if the reaction moves from reactants $\longrightarrow$ to products and it is produced when going from products $\longleftarrow$ to reactants. We can represent this with the following seesaw.



As we added CO_2 the reactants now weigh more and hence the reaction has to proceed to the right $\longrightarrow$. Now imagine we remove some $CO_2(g)$. Again, the equilibrium will be affected and the reaction will restore its equilibrium state by doing the opposite, that is producing $CO_2(g)$ as the reaction proceeds from reactants $\longleftarrow$ to products. Again using the seesaw:



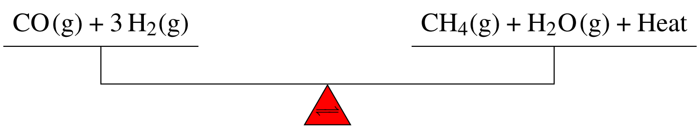
We can also add a different chemical that is not involved in the equilibrium. In this case, the equilibrium will not be affected by this change.

Temperature change

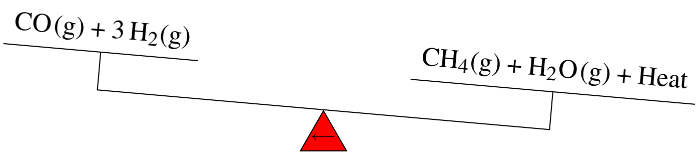
Let us consider the following equilibrium that produces heat–remember we describe these types of reactions as exothermic:

$$CO(g) + 3\,H_2(g) \rightleftharpoons CH_4(g) + H_2O(g) + \text{Heat}$$

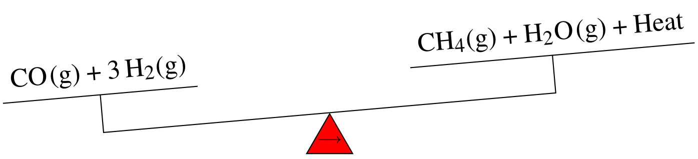
Again, this reaction is in equilibrium so we can use the same seesaw analogy.



If we increase the temperature of the system, the equilibrium will be affected. To go back to an equilibrium state the reaction will decrease the temperature of the container. As the reaction produces heat, a way to decrease the system temperature is to generate reactants ($\longleftarrow$). Again, using the scale that means:



Differently now if we decrease the temperature, the reaction will increase the temperature by going back to its equilibrium state going from reactants $\longrightarrow$ to products. This is because heat is produced as a product

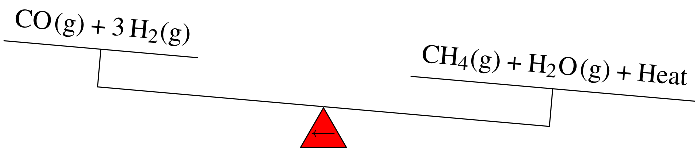


Volume change

We can also think about increasing or decreasing the volume in which the reaction takes place. This change will have an impact on the reaction equilibrium as the concentrations of reactants and products will be altered by this change. Changes in volume will shift the reaction towards the left or right depending on the overall stoichiometric change of the reaction, that is on whether the reaction produces or consumes molecules. For reactions that generate matter, that is, in the case that $\Delta n > 0$, increasing the volume will follow the increase of the number of moles. In other words, by increasing the volume, the equilibrium will shift towards the products, that is towards the right. For reactions that consume matter ($\Delta n < 0$), increasing the volume will shift the equilibrium towards the reactants, that is towards the left. For example, the reaction below consumes molecules:

$$\mathrm{CO\,(g) + 3\,H_2(g) \rightleftharpoons CH_4(g) + H_2O\,(g)}$$

if we increase the volume of the container in which the reaction takes place, the equilibrium will shift toward the left:



The opposite shift will follow a volume decrease as the reaction shift towards the right.

Sample Problem 1

For the next endothermic reaction indicate whether the reaction will shift right ($\longrightarrow$) or left ($\longleftarrow$) after the following changes:

$$\mathrm{N_2(g) + O_2(g) + Heat \rightleftharpoons 2\,NO\,(g)}$$

(a) adding reactants (b) adding products (c) decreasing the temperature.

SOLUTION

(a) Adding reactants always displaces the equilirbium so that reactants are consumed, hence the reaction will proceed $\longrightarrow$. (b) After adding products the reaction will tend to reduce the amount of products, and hence it will go $\longleftarrow$. (c) The reaction is endothermic that means that it consumes heat. If we decrease the temperature it will tend to increase the temperature and hence heat needs to be formed. This will only happen if the reaction proceeds ($\longleftarrow$).

STUDY CHECK

For next exothermic reaction indicate whether the reaction will shift right ($\longrightarrow$) or left ($\longleftarrow$) after the following changes:

$$\mathrm{C\,(g) + O_2(g) \rightleftharpoons CO_2(g) + Heat}$$

(a) removing reactants (b) removing products (c) decreasing the temperature.

D. Procedure

1. Factors that affect the chemical rate. Effect of temperature The goal of next three mini-experiments is to identify the factors that impact the rate of a chemical reaction. Reactions proceed at a certain rate, some are fast others are slow. By playing with a few factor you can increase the speed of a reaction generating more products in less time, or even slow down a reaction, avoiding the formation of products. You will study three different reaction and address the impact of three factors (1) the concentration of reactants, (2) temperature and (3) adding a catalyst on the chemical rate. This mini-experiment addresses the impact of temperature on reaction rate of the decomposition of sodium hydrogen carbonate:

$$\mathrm{NaHCO_3(aq) + H_3O^+(aq) \longrightarrow CO_2(g) + 2\,H_2O(l)}$$

Step 1: – Place 10mL of 0.1 M HCl in each of two different test tubes.

Step 2: – Place one of the test tubes in a cold bath with ice–this is a 400mL beaker half-filled with ice and water. Cool the test tube to a temperature of 10°C.

Step 3: – Place the second test tube in a hot bath–this is a 400mL beaker half-filled with hot water from the tab. Warm up the test tube to a temperature close to 40°C.

Step 4: – Remove both test tubes and place them in a test tube rack. Immediately, add one scoop of $NaHCO_3$ (sodium bicarbonate or sodium hydrogencarbonate) to each tube. You will observe the appearance of bubbles. Write down which test tube produces bubbles first.

2. Factors that affect the chemical rate. Effect of reactant concentration This mini-experiment addresses the impact of temperature on reaction rate of the reaction of magnesium with hydrochloric acid:

$$\mathrm{Mg(s) + 2\,HCl(aq) \longrightarrow MgCl(aq) + H_2(g)}$$

Step 1: – Place a 1-in piece of Mg in each of three different test tubes. Label each test tube 1 to 3.

Step 2: – Measure 10mL of 1M HCl in a graduated cylinder and add it to test tube 1. Immediately, start recording the time and stop when all Mg has disappeared.

Step 3: – Repeat the previous step but now with 2M HCl and then 3M HCl. Write down the three different times in the table below.

3. Factors that affect the chemical rate. Presence of a catalyst. This mini-experiment addresses the impact of catalysts on the reaction rate of the decomposition of hydrogen peroxide:

$$\mathrm{2\,H_2O_2(aq) \longrightarrow O_2(g) + 2\,H_2O(l)}$$

You will add different possible catalysts into the reaction mixture and study where more oxygen bubbles are being produced.

Step 1: – Place 2mL of 3% H_2O_2 into each of five different test tubes. Label the test tubes from 1 to 5. Test tube 1 will be the reference test tube.

Step 2: – Add a small spatula tip of MnO_2 to test tube 2 and record your observations in comparison to test tube 1. If you see more bubbles than on test tube 1 that would mean the substance you used is a catalyst.

Step 3: – Repeat the previous step now using a set of possible catalysts in the table below. Record your observations. If you see more bubbles than on test tube 1 that would mean the substance you used is a catalyst.

4. Le Chatelier principle Reaction proceed from reactants to products but when products are former, reactions can also proceed from products to reactants. This establishes an equilibrium. When a reaction reached equilibrium, the forward and reverse reactions proceed at the same speed, so what is formed is also being consumed. You can alter a reaction in equilibrium pushing chemistry to the right of to the left so that mostly reactants or mostly products are being formed. You can do this by adding or removing reactants or by increasing or decreasing temperature. Le chatelier principle rationalizes the behavior of chemical reactions in equilibrium predicting the shift of the equilibrium. When reactants are added the reaction shifts to the right, when products are added the reaction differently shifts to the left. When reactants are removed, the reaction shifts to the left, and when products are removed it shifts to the right. In this mini-experiment you will address the impact of an equilibrium shift for the following reaction:

$$\underbrace{\mathrm{Fe^{3+}(aq)\ +\ SCN^{-}(aq)}}_{\text{yellow}} \rightleftharpoons \underbrace{\mathrm{FeSCN^{2+}(aq)}}_{\text{red}}$$

Step 1: – Measure 10mL of 0.01M $Fe(NO_3)_3$ and 10mL of 0.01M KSCN in a graduated cylinder. Pour both into a small beaker. Set up four test tubes in a rack add 3mL of previous mixture into each test tube. Label the test tubes from 1 to 4.

Step 2: – Test tube 1 will be the reference. Add 10 drops of water to this test tube.

Step 3: – Add 10 drops of 1M $Fe(NO_3)_3$–this is a product–to test tube 2. Record the color in comparison to test tube 1.

Step 4: – Add 10 drops of 1M KSCN–this is a product–to test tube 3. Record the color in comparison to test tube 1.

Step 5: – Add 10 drops of 1M HCl to test tube 4. This will remove Fe by forming $FeCl_4^-$. Record the color in comparison to test tube 1.

STUDENT INFO

Name: ______________________ Date: ______

Pre-lab Questions

Reaction Rates & Chemical Equilibrium

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1. Define speed of reaction.

2. Define forward reaction and reverse reaction.

3. For the following reaction, write down the forward reaction and the reverse reaction:

$$CO_2(g) + H_2O(l) \rightleftharpoons HCO_3{}^{-}{}_{(Aq)} + H^{+}(Aq)$$

STUDENT INFO

Name: ______________________ Date: ______

Results
EXPERIMENT

Reaction Rates & Chemical Equilibrium

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1. Factors that affect the chemical rate. Effect of temperature

Test tube (Hot/Cold)	Observation (intense/weak bubble formation)

2. Factors that affect the chemical rate. Effect of reactant concentration

Molarity of HCl	Total Time

3. Factors that affect the chemical rate. Presence of a catalyst.

Test tube	Observation (bubbles/no bubbles)	Catalyst (yes/no)?
Reference		
MnO_2		
Zn		
Fresh potato		
Boiled potato		

4. Le Chatelier principle

Test Tube (1,2,3,4)	Color	Color vs reference (Deeper or lighter)	Equilibrium shift ($\longrightarrow$ or $\longleftarrow$)
		N/A	

STUDENT INFO

Name: ______________________ Date: ______

Post-lab Questions

Reaction Rates & Chemical Equilibrium

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1. What is the impact of temperature on the reaction rate?

2. What is the impact of adding a catalyst on the reaction rate?

3. For the reaction below write down the expression of K_c

$$H_2CO_{3(aq)} \rightleftharpoons HCO_3{}^-{}_{(Aq)} + H^+_{(Aq)}$$

4. The chemical equilibrium that controls the PH of blood is

$$CO_{2(g)} + H_2O_{(l)} \rightleftharpoons HCO_3{}^-{}_{(Aq)} + H^+_{(Aq)}$$

   Respiratory alkalosis is caused by a lack of carbon dioxide in the blood that results from poor lung function or depressed breathing. When a patient has respiratory alkalosis, breathing from a paper bag can help. Based on the equilibrium, explain why this simple technique works.

5. In the miniexperiment 1, how did temperature affect the bubble production and why?

6. In the miniexperiment 2, how did molarity affect the time for Mg to dissapear and why?

7. In the miniexperiment 3, how do you explain the catalytic activity difference of fresh and boiled potatoes?